From Cosmic Dawn To Milkomeda, And Beyond

The thoughts of Harvard theorist Avi Loeb traverse the universe, past and future—and he urges young researchers to be just as daring

CAMBRIDGE, MASSACHUSETTS—A file cabinet drawer in the office of Abraham ("Avi") Loeb is simply labeled "IDEAS." It holds a single hanging file with a few manila folders, each containing sheets of paper displaying equations in Loeb's crisp penmanship. "I have ideas all the time; they just bubble up," he says. "I keep adding a piece of paper here if I don't have time to work on it."

In Loeb's 20 years at the Harvard-Smithsonian Center for Astrophysics, those minimalistic sheets have seeded a breadth of research rivaled by few theorists in astrophysics. His prodigious publication record spans three books (including an award-winning popular volume), 430 papers, and counting.

Loeb is best known to cosmologists for illuminating the messy physics of the "cosmic dawn," when light from the first stars and galaxies seared holes into the hydrogen gas that suffused the new universe. He and his many colleagues have also described how to spot ancient gamma ray bursts, how giant black holes may have grown and merged, and how to take the first image of a black hole—key predictions that led to campaigns to observe such extreme physics. But his ruminations have also spawned papers on searching for imprints of life in exoplanet atmospheres, detecting light from nearby alien civilizations, and how astronomers of the far future might deduce the expansion history of the universe.

Loeb tries to foster this mix of serious data-driven theory and adventuresome projection among students and researchers at Harvard's Institute for Theory and Computation (ITC), which he directs. "Following Avi's work can be quite dizzying," says Mordehai Milgrom of the Weizmann Institute of Science in Rehovot, Israel, one of Loeb's first tutors in astrophysics. Adds Frederic Rasio, an astrophysicist at Northwestern University in Evanston, Illinois: "There is hardly a question in astrophysics—any subject, really—that Avi has not touched at some point."

Plucked from the farm

The 51-year-old Loeb traces his far-flung musings to his childhood on a village farm in Israel, about 20 kilometers from Tel Aviv. His father was head of Israel's industry for pecans; the family also raised chickens and grew oranges and grapefruits. After collecting eggs and doing other chores with his two older sisters, Loeb would drive a tractor into the hills and spend hours reading books by existential philosophers. "I often considered returning," he says. "It's a more relaxing style of living."

At age 18, Loeb was chosen with two dozen other young men for an elite Israeli military program called Talpiot. He studied physics and mathematics at the Hebrew University of Jerusalem and underwent basic training in paratrooping, driving tanks, and other soldiering. During and after his graduate program he worked at the Soreq Nuclear Research Center, where he led a weapons project to propel masses using electric discharges to ignite material with lower atomic weight than gunpowder, such as polyethylene. He earned a Ph.D. in plasma physics at age 24 and completed his compulsory service 2 years later.

Loeb's innovations at Soreq caught the attention of U.S. Air Force Gen. James Abrahamson, who came to Israel as the first director of President Ronald Reagan's Strategic Defense Initiative program. The general's staff invited Loeb to visit the United States, where the era's leading plasma physicist, Marshall Rosenbluth, steered him toward the Institute for Advanced Study (IAS) in Princeton, New Jersey. There, noted astrophysicist John Bahcall first invited Loeb for a 1-month stay, then stunned him with an offer of a 5-year appointment—but only if Loeb switched from plasma physics to astrophysics. Loeb marvels at the "wild risk" that Bahcall, who died in 2005, took in hiring him. "I owe him my career," he says.

From IAS, Loeb took an assistant professor job at Harvard in 1993, despite warnings that promotion was improbable. "At the time, Harvard viewed junior faculty almost as a glorified postdoc," says Harvard astrophysicist Jonathan Grindlay. "It was not a healthy environment." But nearly 4 years later, when Loeb had tenure offers from Cornell University and the Weizmann Institute, Harvard made the rare decision to keep him. "He said we would be glad we hired him," chuckles Robert Kirshner, the astronomy department chair at the time. "Avi has mellowed a bit, but this great self-confidence has remained in place."

From darkness to light

Loeb's promotion came at a time of profound personal change. He divorced his first wife, who lived separately in New York in a marriage that never had worked, and months later met Ofrit Liviatan in Israel—through a connection arranged by the pair's mothers. Liviatan, a lawyer in Israel, joined Loeb in Cambridge a year later. She now lectures in Harvard's Department of Government.

CREDIT: CLIVE GRAINGER

Published by AAAS

The Loeb files. At home in 1966 in Beit Hanan, Israel, with sister Shoshana; at the Hebrew University of Jerusalem in 1982 during Talpiot military training (*Loeb at rear left*); playing soccer in 2009 with Harvard University colleagues.

CREDITS (FROM LEFT): FRITZ COHEN/THE ISRAELI NATIONAL PHOTO COLLECTION; COURTESY OF AVI LOEB; ITC PHOTO ARCHIVE

The couple lives in a quiet setting in Lexington, about 20 minutes outside Boston, with daughters Klil, age 11, and Lotem, age 7. Loeb works on their 110-year-old house and watches the sky from his back porch, amid a constant flow of ideas. "One day it may stop," he says. "But so far, it hasn't."

Many of those ideas concern the "epoch of reionization"—the long era when ultraviolet light from stars and galaxies split the universe's dark fog of neutral hydrogen into protons and electrons, starting about 100 million years after the big bang. In papers establishing a now-accepted paradigm, Loeb and his many students and postdocs built up the physics of how ionized hydrogen "bubbles" spread into ever-evolving patterns as stars and quasars lit up, like a cosmic sponge growing more porous with time.

The leftover neutral hydrogen emitted a hum of radiation at a wavelength of 21 centimeters. Loeb's calculations suggested that low-frequency radio antennae on Earth could tune into that hum, stretched out up to 3 meters long on its way here by the ongoing expansion of space. The more distant the hydrogen, the more its humming gets stretched. Loeb probed in detail how astronomers could harness that "redshift" to create a tomographic atlas of the hydrogen fog burning off during the cosmic dawn, a process that took up to a billion years.

Colleagues credit Loeb for the theoretical underpinnings supporting major radio-astronomy efforts in Australia, Europe, and South Africa to unveil those patterns. "Avi has done more than anybody to explain how important this period of time was and what facilities would be needed to unravel the physical detail of what happened," says astronomer Richard Ellis of the California Institute of Technology in Pasadena.

Loeb takes as much pride in two other pursuits that helped chart a course for observers. In a 1992 study at IAS, Loeb and Andrew Gould, who is now at Ohio State University, showed that planets circling other stars could reveal themselves by causing brief flares of light from background stars via gravitational "microlensing"—still the only method that exposes exoplanets in distant parts of the Milky Way. And about a decade ago, Loeb and colleagues calculated that gamma ray bursts—the most powerful explosions known—near the margins of the observable universe should remain visible to telescopes. NASA's Swift satellite soon confirmed the predictions.

The studies reflect an unshakable tenet of Loeb's work: contact with data. He avoids the mathematical conjectures of what he calls "theory bubbles," and he steers students away from them as well. "There is one reality out there," he says. "It's dangerous to work on abstractions with no feedback from data. Some physicists do not understand this."

Astro-venture capital

Even Loeb's riskier papers—which gain far more public notice—are grounded in physics that extrapolates from today's data. For example, he and ITC postdoctoral fellow T. J. Cox, who is now at the Carnegie Observatories in Pasadena, simulated the crash of the Milky Way and our galactic neighbor, Andromeda, starting in about 2 billion years. Our solar system, they deduced, would probably be tossed near the outskirts of the giga-galaxy, which Loeb dubbed "Milkomeda." In the far future, he calculated, the relentless acceleration of the universe due to dark energy would render all other galaxies invisible. Still, he claimed in a recent paper, Milkomedan astronomers could retrace what had happened by studying light from closer stars ejected from the merged galaxy by its giant central black hole.

Lately, Loeb has been drawn to the prospects of detecting life elsewhere. One signpost would be spectral traces of oxygen in the atmosphere of a rocky world. According to Loeb and astrophysicist Dan Maoz of Tel Aviv University, NASA's upcoming James Webb Space Telescope could spy that faint signal from planets orbiting white dwarfs, the dense Earth-size remnants of stars like our sun. In another E.T.-tinged study, Loeb and Princeton astrophysicist Edwin Turner proposed using future telescopes to look for "city lights" from other civilizations—and testing the method now by scanning the outskirts of our solar system.

Some colleagues compare him to visionary physicist Freeman Dyson of IAS, but Loeb knows that many others regard such speculative work with raised eyebrows or worse. "But frankly, I don't care," he says. Creativity and challenging convention spur the best research, he says. Federal funding agencies have lost sight of this, Loeb says, dooming pioneering missions like the Laser Interferometer Space Antenna to detect gravitational waves.

In a recent paper, Loeb made waves by urging young astrophysicists to devote 20% of their research to innovative "venture capital" projects outside the mainstream. "It requires a certain amount of bravery to come up with these things," Milgrom of the Weizmann Institute says. "People are afraid to do risky work, but words from Avi can be influential."

Loeb now has less time to publish papers at will. In addition to directing ITC, he is chair of the Harvard astronomy department. At ITC, his peers note, Loeb has built a team that is at once high-powered and collegial. Prize-winning postdoctoral fellows and graduate students like what they see. "They get all the best young people now," a colleague says privately. "No one can compete with them."

Despite the demands, notions keep coming to Loeb in his shower and on his porch. Now, edging ever closer to Earth, he and a co-author are honing a new theory of how the moon formed. "I still have a niche: ideas that other people do not think about," he says with a smile. "There is room for innovation"—and for another sheet in the file drawer.

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