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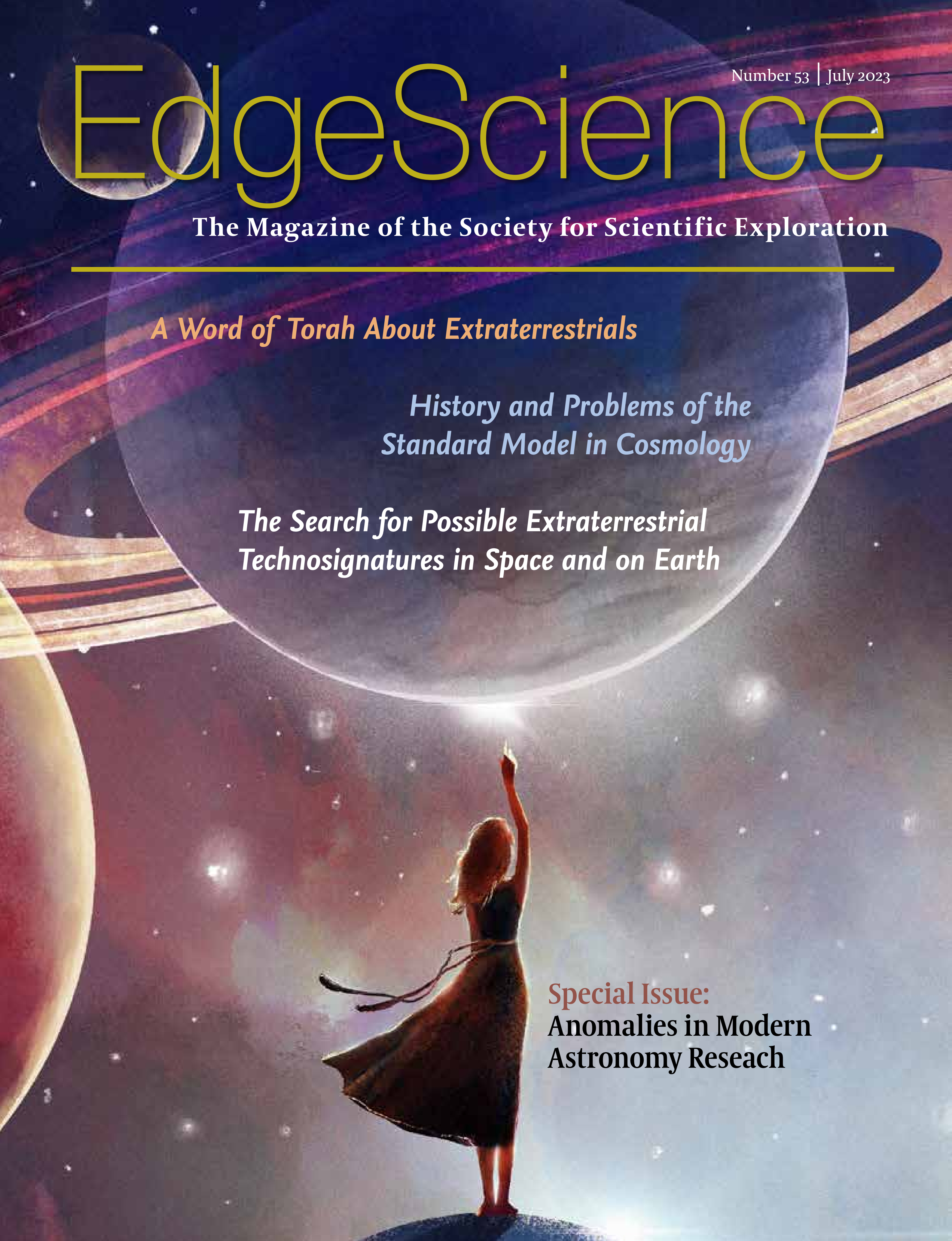

A Word of Torah About Extraterrestrials

History and Problems of the Standard Model in Cosmology

The Search for Possible Extraterrestrial Technosignatures in Space and on Earth

Special Issue:
Anomalies in Modern Astronomy Reseach

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Why EdgeScience? Because, contrary to public perception, scientific knowledge is still full of unknowns. What remains to be discovered—what we don't know—very likely dwarfs what we do know. And what we think we know may not be entirely correct or fully understood. Anomalies, which researchers tend to sweep under the rug, should be actively pursued as clues to potential breakthroughs and new directions in science.

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Avi Loeb

A Word of Torah About Extraterrestrials

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Spirituality and the frontiers of science have something in common: they both explore the unknown. This is not an easy task. It is far more comforting to explore what is known. We know all about the ordinary matter that makes luminous stars, but some scientists search for dark matter without knowing its nature. We do not know whether there are sentient extraterrestrials, but some scientists search for them.

The unknown brings existential risks. But given that we live for such a short time, less than a part in a hundred million of cosmic history, the fundamental choice is between living a comfortable and predictable life or charting a road not taken with the glimmer of hope that it will offer new revelations. Anything discovered along the unbeaten path will be our own. As Frank Sinatra sang: “And now the end is here/ And so I face that final curtain/My friend I’ll make it clear/I’ll state my case, of which I’m certain/I’ve lived a life that’s full/I traveled each and every highway/And more, much more/I did it, I did it my way.”

There are two fundamental differences between spirituality and science. Whereas spirituality is guided by a personal experience, science is guided by a universal experience. In the former, the unique interaction between the individual and the world dictates the outcome, whereas in the latter, it is a realization that can be shared equally by all scientists. Whereas the spiritual experience is fresh and unique to an individual, the scientific experience is universally shared by all scientists once discovered. The dialogue with God is an “I and Thou” experience, unique to the individual, in Martin Buber’s existential philosophy. The bending of light by clusters of galaxies implies the presence of dark matter to all scientists who adopt Albert Einstein’s theory of gravity.

Another difference involves the nature of evidence. In science, reliable evidence must be quantitative, reproducible, and collected by instruments that are fully calibrated and under control. However, spirituality revolves around the human experience and does not rely on instrumentation as the mediator of revelations.

For these reasons, I was surprised to receive an email from Rabbi Elyssa Joy Austerklein, starting with the sentence: "With admiration and respect, I want to share with you my Dvar Torah from Yom Kippur, which highlights your book *Extraterrestrial*." Dvar Torah (meaning `A Word of Torah' in Hebrew) is an essay based on the weekly portion of the *Hebrew Bible*. The Mishnah (Avot 3:3) states that a table over which no Dvar Torah is shared is compared to an altar upon which offerings are brought to idols; conversely, a table where D'var Torah is spoken is akin to God's table. In today's terminology, "no Dvar Torah" would be equivalent to the common threads regarding idols on social media.

Elyssa's inspiring essay pays special attention to the statement from my book: "If you don't expect the unexpected, you'll never see it." She gives it the proper interpretation: "We need to be constantly aware of our limits and be seeking to expand them. If we are sure that what we experience or know is as we predicted, then we don't leave room for growth.... Sometimes we think that we are open to what we don't know or haven't experienced before, but really we are just trying to prove what we already believe or know. We haven't made the space for the unknown. We haven't expected the unexpected…how does our desire to predict and control actually affect the outcome? How do our calculations, at times, actually determine the course of events?" She adds: "Astrophysicist Dr. Loeb also said: 'Truth and consensus may never be conflated.' As a society, we are dangerously falling prey to this conflation." And she concludes by stating: "We must venture into the unknown… On this Yom Kippur day, as we empty our bodies of physical sustenance, may we empty ourselves of preconceptions and begin a new journey towards expecting the unexpected—Gmar Chatimah Tovah—May you be sealed in the Book of Life."

What unifies spirituality and our scientific study of the Universe is a sense of awe and humility. No, we are not at the center of the stage, and we arrived at the cosmic play after 13.8 billion years, so how can we imagine that the play is about us? Indeed, the Earth-Sun system is not unique or privileged. But many of us still insist on owning the last territory on which our ownership is disputed as of yet: "Yes, we are the only sentient beings in the Universe."

Wedding event stock photo/Shutterstock.com

Hand of a bonobo doing a blessing sign. dcaillat/Shutterstock.com

Well, let me offer some breaking news on this last item. Within this century, Artificial Intelligence (AI) systems will likely appear sentient in the most elaborate Turing Tests that the human mind can imagine. Within this century, astronomers are likely to discover evidence for a smarter kid on our cosmic block, not in the form of radio signals but in the form of weird interstellar objects—identified by the advanced AI algorithms of the Galileo Project. And finally, within this century, we might realize that other sentient beings already exist on Earth. So far, bonobos were educated to communicate with us in our language, but AI systems can be used to educate us about their language. All in all, AI systems will serve as our tutor, bringing the next Copernican revolution in which we would realize that consciousness and sentience are emergent phenomena shared by non-humans.

Given our status as inconsequential spectators of the cosmic scene, what should we do? We could celebrate the metaphorical routine of "eating leaves in our jungle," as bonobos did for nearly a million years. Or we can explore the unknown, expecting the unexpected. The choice is ours.

Andreas Leitner

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Martín López-Corredoira

History and Problems of the Standard Model in Cosmology

Since the beginning of the 20th century, a continuous evolution and perfection of what we today call the standard cosmological model has been produced, although some authors like to distinguish separate periods within this evolution. A possible historical division of the development of cosmology into six periods was proposed by Luminet (2008): (1) the initial period (1917–1927); (2) the period of development (1927–1945); (3) the period of consolidation (1945–1965); (4) the period of acceptance (1965–1980); (5) the period of enlargement (1980–1998), and (6) the period of high-precision experimental cosmology (1998–).

The Initial Period (1917–1927)

At the beginning of the 20th century, two great achievements in physics and astronomy initiated the journey toward the standard cosmological model as we know it today. The first was the observational evidence for the existence of many galaxies separated by very large distances—much larger than the usual distances managed by astronomers previously—the Milky Way thus being only one galaxy among many. It was definitively established after a period of discussion that finished with the Great Debate in 1920 between the American astronomers Heber D. Curtis

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Night landscape with colorful Milky Way and yellow light at mountains.

(1872–1942), who defended the hypothesis that some nebulae (now called galaxies) were not part of the Milky Way but were located at very large distances from it, and Harlow Shapley (1885–1972), who claimed that these nebulae were part of the Milky Way. This achievement gave rise to the subsequent development of extragalactic astronomy, and, implicitly, a new cosmological vision was emerging out of this scenario: a vision of a Universe of vast spaces, impossible to imagine, where galaxies are the fundamental components in a larger-scale structure.

The other great achievement came from physics in the form of Albert Einstein's (1879–1955) general relativity. Certainly, his earlier theory of special relativity was also very important, but for astronomy, particularly from the perspective of cosmology, general relativity was the long-awaited breakthrough. Newton's magnificent achievements had blocked the free expansion of cosmological ideas because of the problems in solving the stability of systems without an eventual collapse and having recourse to godly intervention.

The models that would constitute the basis of our present standard cosmology came a little later. The basic idea assumed is that the current Universe is homogeneous on a large scale and that the distances among all the different objects are currently growing owing to the expansion of the Universe, a recession of objects with respect to one another on a large scale. On small scales, different objects could cluster together because their gravitational attraction overcomes the expansion. The Russian physicist Alexander Friedmann (1888–1925) developed the basic aspects of the application of general relativity to a cosmological model (Friedmann 1922, 1924).

The Period of Development (1927–1945)

In 1924, the German astronomer Carl Wirtz (1876–1939) noted a correlation between the faintness of a galaxy and its redshift. Edwin P Hubble (1889–1953) and Milton Humason (1891–1972) measured the distance of a number of galaxies during the same year and would later find the famous Hubble–Lemaître law of the linear relationship between radial velocities and distances. The redshifts were interpreted as proof of the expansion of the Universe (Hubble, 1929). Prior to Hubble's publication in 1927, the Belgian Catholic priest, physicist, and astronomer Georges Lemaître (1894–1966) developed a theoretical model of an expanding Universe in an extension of the work of Friedmann. The work by Lemaître (1927) was published in French in a small Belgian journal, and also tells us about the recession of galaxies and the recession rate in the linear velocity–distance relationship, including an analysis of observational data, as rediscovered later by Hubble in 1929.

Another line of development of the cosmological model was suggested by the Japanese physicist Seitaro Suzuki, who suggested that the observed helium–hydrogen ratio might be explained "if the cosmos had, at the creation, the temperature higher than 10^9 degrees" (Suzuki, 1928). Lemaître, in 1931, with the expansion and the arrow of time from the second law of thermodynamics in mind, developed his concept of the 'primeval atom' (Lemaître, 1931), the first version of what later would be called the "Big Bang." According to him, the initial state of matter in the Universe might be thought of as a sea of neutrons. Lemaître thought that cosmic rays were relics of primordial decays of atoms, which was later demonstrated to be wrong. Moreover, his ideas on stellar evolution were also demonstrated to be wrong during the 1930s. So, by the end of the decade, the primeval-atom hypothesis had been generally rejected by the scientific community.

...the name "Big Bang" was not given by Gamow, but by one of the opponents of his theory, Fred Hoyle (1915–2001), who dubbed Gamow's primeval atom theory as the "Big Bang," in order to ridicule it.

The Period of Consolidation (1945–1965)

After World War II, George Gamow (1904–1968), a Russian physicist who emigrated to the US in 1934, compared the detonation of an atomic bomb with the origin of the Universe and popularized the Big Bang theory (Gamow, 1947). In fact, the name "Big Bang" was not given by Gamow, but by one of the opponents of his theory, Fred Hoyle (1915–2001), who dubbed Gamow's primeval atom theory as the "Big Bang," in order to ridicule it. Gamow and one of his students, Ralph Alpher (1921–2007), published a paper in 1948. Gamow, who had a certain sense of humor, decided to put the reputed physicist Hans Bethe (1906–2005) as the second author, even though he had not participated in the development of the paper, so the result was a paper by Alpher, Bethe, and Gamow (Alpher et al., 1948), to rhyme with "alpha, beta and gamma." Later, Robert Herman (1914–1997) joined the research team, but—according to Gamow—he stubbornly refused to change his name to "Delter."

Alpher and Herman (1949) and Gamow (1953) also predicted an early stage of the Universe that would produce relic radiation that could be observed at present as a background in microwave wavelengths, corresponding to the epoch of decoupling of matter and radiation. The first published recognition of relic radiation as a detectable microwave phenomenon was in 1964 by the Russian cosmologists Andrei Doroshkevich (1937–) and Igor Dmitriyevich Novikov (1935–) (Doroshkevich & Novikov, 1964). Then came the official discovery of the cosmic microwave background radiation by Arno Allan Penzias (1933–) and Robert Woodrow Wilson (1936–) (Penzias & Wilson, 1965), although this same radiation had been previously directly or indirectly observed by other researchers.

The Period of Acceptance (1965–1980)

More evidence supporting the standard model of the expanding Universe came from Malcolm Longair (1941–) and Martin Ryle (1918–1984), who argued that the data indicate that the Universe must be evolving (Longair, 1966; Ryle, 1968). The galaxies at high redshift—that is, at great distance—showed distributions and properties different from those at low redshift. Since at larger distances we are observing the past Universe, given the limited speed of light, this implies that the distant galaxies belong to an epoch of the Universe that was much earlier than the present one.

Talking about consensus cosmology, Rudolph Schild once queried, "Which consensus? Do you know who consented? A bunch of guys at Princeton who drink too much tea together"

The confirmation of the predicted microwave radiation and evolution of the Universe gave confidence to those cosmologists who supported the standard model. Many hitherto skeptical physicists and astronomers became convinced they now had a solid theory. By the mid-seventies, cosmologists' confidence was such that they felt able to describe in intimate detail events of the first minutes of the Universe (Weinberg, 1977). The Period of Enlargement (1980–1998)

Nonetheless, there were problems that remained to be solved, such as why the Universe appeared to be the same in all directions (isotropic), why the cosmic microwave background radiation was evenly distributed, and why its anisotropies were so small. Why was the Universe flat and the geometry nearly Euclidean? How did the large-scale structure of the cosmos originate? Clearly, work on the fundamental pillars of the cosmological edifice remained to be done. In the 1970s and 1980s, proposals were brought forth to solve these pending problems, with inflation as the leading idea in the solution of cosmological problems at the beginning of the Universe, and the idea of non-baryonic dark matter as a new paradigm that allows the theory to fit the numbers of some observations. Grand Unified Theories of particle physics would also support the existence of CP violation (asymmetry of matter and antimatter) or non-baryonic dark matter. Also, the joining of cosmology and particle physics and scenarios containing baby universes, wormholes, superstrings, and other exotic ideas were born. This excess of theoretical speculation, not based on observations, has led some authors to call this epoch the era of post-modern cosmology (Bonometto, 2001). This union between cosmology and particle physics is due in part to the halting of particle physics experiments because of their escalating cost, a situation that led many particle physicists to move over into cosmology, wishfully contemplating the Universe as the great accelerator in the sky (Disney, 2000; White, 2007). Alas, particle physicists lack the necessary astronomical background—complained Mike Disney—to appreciate how soft an observational, as opposed to experimental science, necessarily has to be.

In the 1990s, a third patch was applied to the theory in an effort to solve new inconsistencies with the data in the form of dark energy, which supposedly produced acceleration in the cosmic expansion. The problems to be solved were basically the new Hubble–Lemaître diagrams with type Ia supernovae as putative standard candles, the numbers obtained from cosmic microwave background radiation anisotropies, and especially estimates of the age of the Universe, which were inconsistent with the calculated ages of the oldest stars.

The renovated standard model, including these ad hoc elements, would come to be called the ΛCDM cosmological model, where Λ stands for dark energy, and CDM stands for cold dark matter, the favored subgroup of models of non-baryonic dark matter. Some cosmologists referred to it as "concordance cosmology: to emphasize that this model is in agreement with all the known observations. Other authors, critical of the standard model, prefer to call it "consensus cosmology," wishing to emphasize that this new cosmology is, above all, a sociological question of agreement among powerful scientific teams in order to establish the orthodoxy of a fundamental dogma. This agreement would be mainly between two powerful cosmological groups, the teams dedicated to the analysis of supernovae and the cosmic microwave background, who found a rough coincidence in the necessary amount of dark energy, although with large error bars, that reinforced their belief that they had discovered an absolute truth, thus compelling the rest of the community to accept this truth as a solid standard, while at the same time discarding the results of other less powerful

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cosmological groups that presented different values of the parameters. Talking about consensus cosmology, Rudolph ('Rudy') Schild (1940–) once queried, "Which consensus? Do you know who consented? A bunch of guys at Princeton who drink too much tea together" (Unzicker & Jones, 2013, ch. 3).

The Period of High-Precision Experimental Cosmology (1998–)

Rather than major discoveries or proposals, this epoch is characterized by a lack of discussion on the fundamental ideas in cosmology, when it becomes a tenet of belief that all the major problems have been solved. This state of complacency has resulted in excess confidence in the robustness and superiority of the standard model, with little consideration for alternative models. Certainly, some minor topics are being debated, such as the equation of the state of dark energy, and the types of inflation or the coldness or hotness of dark matter, but these are subtleties (Byzantine arguments) within the major fundamental scheme. This is the epoch in which the main enterprise of cosmology consists of spending big money on megaprojects that will achieve accurate measurements of the values of the cosmological parameters and solve any small problems that remain to be explained.

This is also the epoch of the highest social recognition of cosmology: Not only do schools, museums, and popular science journals talk about the Big Bang as well established, to be compared to Darwin's evolution and natural selection theory, but cosmology now occupies a privileged ranking among the most prestigious natural sciences. For instance, cosmology and its four dark knights (CP violation, inflation, non-baryonic dark matter, and dark energy) have been awarded Nobel Prizes in Physics in 2011 and 2019, respectively, for the putative discovery of the dark energy that produces the acceleration of the expansion, and the inclusion of the dark components in our understanding of the Universe. One may wonder whether unconfirmed quasi-metaphysical speculations should properly form part of the body of the recognized knowledge of physics, leaving behind the conservative tradition of Nobel committees not awarding prizes for speculative proposals. Einstein did not receive either of his Nobel Prizes for his discovery of special and general relativity; neither did Curtis for his definitive recognition of the true nature of galaxies in the Great Debate of 1920. Neither Lemaître nor Hubble received the Nobel Prize for their discovery of the expansion of the Universe, but we now have committees that give maximum awards for highly speculative proposals, such as the acceleration of the expansion of the Universe, the reality of which has yet to be confirmed. We certainly do live in a very special time for cosmology.

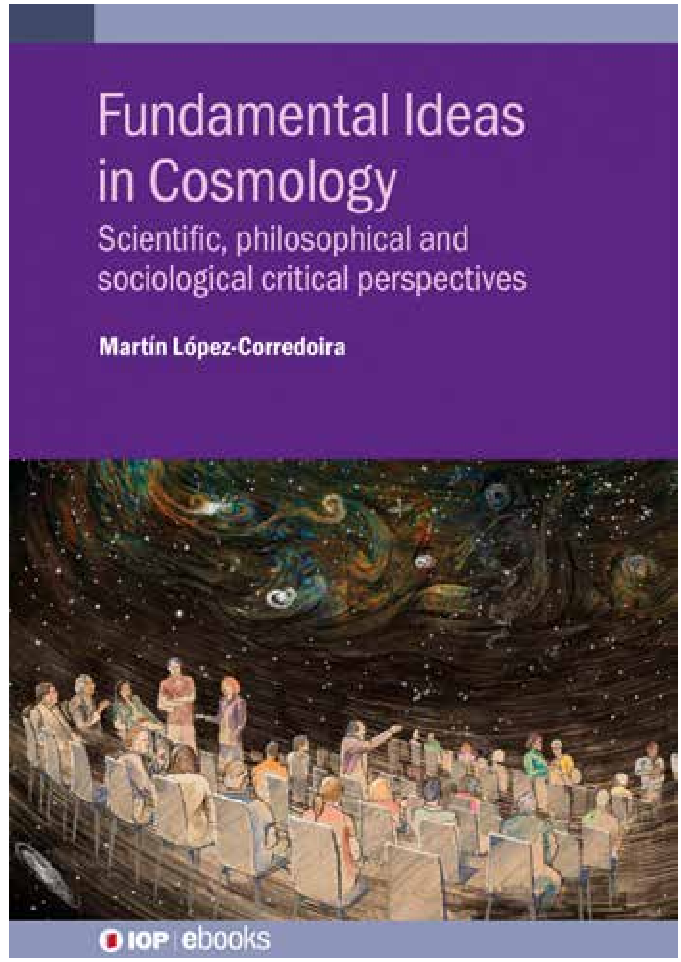
However, this brand of epistemological optimism has declined with time, and the expression "crisis in cosmology" is stubbornly reverberating in the media. The initial expectation of removing the pending minor problems arising from the increased accuracy of measurements has backfired: the higher the precision with which the standard cosmological model tries to fit the data, the greater the number of tensions that arise, the problems proliferating rather than diminishing. Moreover, there are alternative explanations for most of the observations.

At the Anomalies in Modern Astronomy Research online symposium organized by the Society of Scientific Exploration (October 22nd, 2022), Prof. Pavel Kroupa presented anomalies from galactic to Gpc scales (large-scale structures), including some examples of 5σ tensions and some mention of Modified Newtonian dynamics (MOND) as an alternative to standard gravity and dark matter. We can complement the range of anomalies in cosmology with further cases of Cosmic Microwave Background Radiation, nucleosynthesis, tests of expansion, CP violation, inflation, and other topics. There is no space in the present text to discuss in detail these topics; the reader interested in these anomalies and tensions can read the recent literature on the collections of problems of the standard model: (Perivolaropoulos & Skara, 2022; Abdalla et al., 2022; Melia, 2022; López-Corredoira, 2017, 2022).

CP violation has problems; There is no experimental evidence for a finite lifetime of a proton below 10^{34} years (Tanaka et al., 2020). Inflation has problems; Some authors have argued that the inflation necessary to explain a flat Universe is highly improbable (Iljas et al., 2017). Hubble–Lemaître diagrams with type Ia supernovae can be explained without dark energy (López-Corredoira & Calvo-Torel, 2022); also, dark energy can be avoided in other observations.

The standard interpretation of the redshifts of galaxies is that they are due to the expansion of the Universe plus peculiar motions, but there are other explanations, such as the "tired light" hypothesis, which assumes that the photon loses energy owing to some unknown photon–matter process or photon–photon interaction when it travels some distance. Different observational tests give different results, although none of them so far provides strong proof in favor of a static Universe (López-Corredoira, 2017; López-Corredoira, 2022, ch. 4). The discussion on anomalous redshifts is also inconclusive.

Doubt is cast upon that precision cosmology derived from Cosmic Microwave Background Radiation analysis, owing to the difficulties in making maps totally free from foreground contamination. Moreover, many alternative explanations of its origin are found in the technical literature, and certain observed anomalies, such as the lack of low multipole signal, alignment of quadrupole and octupole, and others, are at odds with the standard model (Schwarz et al., 2016), which opens the door to possible fundamental



errors in the standard cosmological description of this radiation.

In the standard model, it is claimed that helium-4, lithium-7, and other light elements were created in the primordial Universe, and the existence of these elements was used as proof for the necessity of a hot Universe in its first minutes of life. However, only helium-4 has had successful direct confirmation of the predictions, although at the price of requiring a baryon density raises other problems. The observed abundance of lithium-7 is 3 to 4 times lower than predicted (Coc et al., 2012). The other light elements are affected by uncertainties in the theoretical model or by later creation or destruction associated with stellar nucleosynthesis, cosmic rays, or other astrophysical processes, so they cannot be used to corroborate cosmological predictions. Moreover, there are alternatives to primordial nucleosynthesis to explain the observed abundances, even for helium-4 (Adouze et al., 1985; Burbidge & Hoyle, 1998).

Cosmology is not a science like others since it contains more speculative elements than is usual in other branches of physics, with the possible exception of particle physics. The goal of cosmology is also more ambitious than routine theories in physics: cosmology aims to understand everything in our Universe without limit. However, cosmological hypotheses should be very cautiously proposed and even more cautiously received. This skepticism is well-founded. There are scientific, philosophical, and sociological arguments to support this claim (López-Corredoira, 2022).

Some of the material for these articles was excerpted from the book *Fundamental Ideas in Cosmology. Scientific, Philosophical and Sociological Critical Perspectives* (López-Corredoira, 2022).

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Massimo Teodorani

The Search for Possible Extraterrestrial Technosignatures in Space and on Earth

The Universe is very big, and the possibility that we humans are alone in space is logically and scientifically unacceptable. Solar-type stars, whose lifetime can reach up to five billion years, are numerous according to astronomical statistics and can host planets, some of which have already been discovered and placed in the habitability zone where the phenomenon of life can be born and grow. The very long duration of nuclear fuel that is burning in these stars can give enough time for a civilization to develop technologically during one or more evolutionary cycles unless nuclear self-destruction occurs. The laws of physics are the same everywhere in the universe. Therefore, there are good reasons to suppose that their discovery follows very similar paths as ours. In such a way, using, at least in the first phase, electromagnetic waves to communicate, would be a natural process. Assuming that such a technological evolution reaches much higher peaks over a reasonably long time, exploring the universe directly would be natural as well. Science is presently searching for both possibilities.

SETI Research

For at least 40 years, the scientific search for extraterrestrial intelligence has been the prerogative of the SETI project (Search for Extraterrestrial Intelligence), mainly managed by the SETI Institute and directed by astronomers such as Jill Tarter and Seth Shostak. The basic concept of SETI is that to demonstrate the existence of other intelligences, it is necessary to be able to detect evidence showing that our cosmic neighbors are able to send signals in space, either in the form of radio waves—the band of microwaves between 1 and 10 GHz—or in the form of pulsed laser signals in optical wavelengths. Indeed, in order to achieve this result, the standard SETI project is based on the use of both radio telescopes and optical telescopes.

In the first case, the radio telescopes are connected to multi-channel spectrum analyzers capable of scanning 10-100 million frequencies simultaneously with a precision that reaches 1/10 of Hz on a bandwidth that, on average, can be around 10 MHz. This is like looking for a needle in a haystack, since, despite the great penetrative capability of microwaves into interstellar space (without being absorbed), such a signal is disturbed by a whole series of noises, ranging from the emission of cosmic sources up to the interference caused by human emitters such as cell phones. To be sure that it is really an intelligent alien signal, it will not only have to exceed the noise threshold by at least seven times, but it will have to be characterized by a "Doppler effect." In fact, the emitted signal will have to be periodically shifted towards the blue or the red since it is expected that an antenna that is located on a planet, which is rotating and orbiting around its star, sometimes approaches us and sometimes moves away. Obviously, this signal must also have a whole series of other characteristics that allow us to identify it as intelligent; polarization and narrow bandwidth are two of them.

Instead, in the case of optical investigations, pulsed laser signals are sought with a frequency of the order of a nanosecond (one billionth of a second), because particularly advanced civilizations are expected to be able to send from their planet very high-power signals (up to one Terawatt), pulsed and modulated in such a way as to contain a coded message in them. The effect will be the momentary outshining of the mother star during the time in which the laser beam will be aligned with the line of sight. The method of sending pulsed signals also saves energy. In order to detect signals of this kind, it is necessary to connect an optical telescope to a photon counting detector—such as the Multi Pixel Photon Counter that is in use at Lick Observatory, Mt Wilson, California, allowing a very high time resolution.

In both types of investigation, considering that an electromagnetic signal attenuates with the inverse of the square of the distance as the distance from the source increases, using the tools we have available today, we could be able to lock on a signal produced by alien civilizations that are at a distance not exceeding 100-1000 light years, i.e., a distance at least 100 times smaller than the global extension of the Milky Way. Both in the case of radio and optical investigations, it is also essential that any intelligent signals detected by an observer on Earth can be detected continuously—with the exact same celestial coordinates—by any other observer located at different points of the planet. This would represent a validation of the alien reality of the signal.

What has been found in 30 years of tireless investigations using these two research methods? Other than a countless number of false alarms caused by various sources of noise and interference, both internal to the detection instrument and external to it, nothing has been yet revealed (Lazio et al., 2002; Wright, 2022). There is an ongoing plan to improve the situation in the immediate future by increasing the number of detection channels, i.e., increasing the bandwidth and frequency resolution used, increasing the sensitivity of radio receivers and optical photomultipliers, improving the algorithms that are used to analyze the signal, increasing the photon collecting area of radio and optical telescopes, and extending the space on the celestial sphere on which the survey can be carried out at simultaneous times. It may be then that in the not-too-distant future, such an extraterrestrial signal will be detected.

Nevertheless, even if that were the case, what kind of signal would we have detected using these methods? With the highest probability, that would be a signal produced by civilizations that are technologically comparable to ours or a bit more advanced. There is nothing to complain about the canonical search methods used by the SETI protocol; technologically speaking, they are flawless (the author of this article, among other things, has dealt with them in the past). However, looking at things more scientifically, it is not difficult to realize that not only are these methods limited, since there is a tendency to "anthropomorphize" the other possible civilizations, but also that this is certainly a very uneconomical method. Above all, this would be a method affected by a drastic selection effect. This is because a) being able to grasp a civilization in an era of technological development similar to (or slightly superior to) ours would be a really big fluke since it is highly unlikely to be able to detect contemporary civilizations, which would be even more improbable if we look at such limited distances; b) civilizations not yet sufficiently evolved are not yet able to send signals of any kind; c) much more advanced civilizations than ours might have given up radio waves and laser signals long ago since they would be able to visit us directly.

As it can be seen, therefore, the standard SETI project, although characterized by extremely refined sensors and undoubtedly rational tactical procedures, lacks strategy. No wonder then that there have still been no results in 30 years. There are probably smarter ways (strategically and scientifically) to search for extraterrestrial intelligence.

If we limit ourselves to the current expectation that we can look for technological aliens only by trying to pick up signals that they might send from their own planet (intentionally or not), then it can be easily calculated that we would have—in our own galaxy alone—a one in a billion chance of being able to find the evidence of intelligent extraterrestrials. According to the Drake formula, it can be calculated that there are no more than 100 or 1000 technological civilizations in our galaxy, and this is out of a possible 1000 billion planets it contains. The conditions for life are very rare, and even more so for intelligence.

Engineering the Circumstellar Space

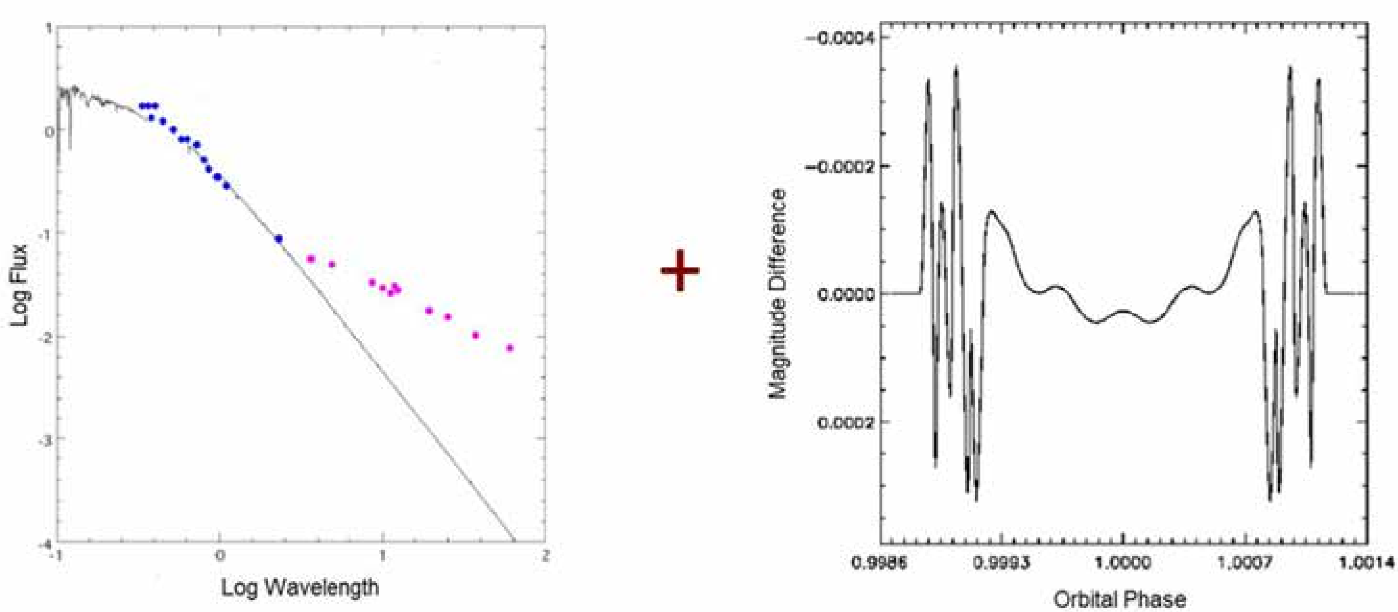
The SETT project (Search for Extraterrestrial Technology) is a relatively recent branch of SETI and has the main goal of searching for evidence of techno signatures from exogenous intelligences. In order to accomplish this task, we must start, as French astronomer Luc Arnold already did with his mathematical simulations, from the photometric study of the light of distant stars in order to verify whether the periodic decrease of their light could be due to periodic occultation caused by the "eclipse" effect produced by large celestial structures of an artificial nature orbiting in front of these distant suns (Arnold, 2005). The shape of the light curve at minima might tell us that the occultation effect is not caused by a planet orbiting around the mother star, but rather by a giant technological structure characterized by a very particular geometry.

At the same time—as a parallel study—we could search for the possible excess of infrared radiation that is expected to be emitted by stars similar to the Sun—usually characterized by a very weak emission in this wavelength window—around which a super-civilization may have built an immense technological grid in order to extract energy.

What has been found in 30 years of tireless investigations using these two [SETI] research methods? Other than a countless number of false alarms caused by various sources of noise and interference…nothing has been yet revealed

Calculations show that such a grid would be able to produce much infrared radiation. This would be caused by a "shell" surrounding the star, made of many orbiting artificial planetoids, and called a "Dyson sphere" (Carrigan, 2004; Dyson, 1960). The shell would partially collect the light coming from the central star and reradiate it at a much lower temperature. The reradiated energy is expected to be an infrared blackbody spectrum with a characteristic temperature in the range of 150-500 °K. Solar-type stars have a hydrostatically stabilized structure, with no mass loss and consequently with no circumstellar envelope. If we found one which was manifested by an infrared excess, then that can only be due to an artificial structure.

Both manifestations—peculiar light curves and infrared excess from stars of a solar spectral type—can be studied

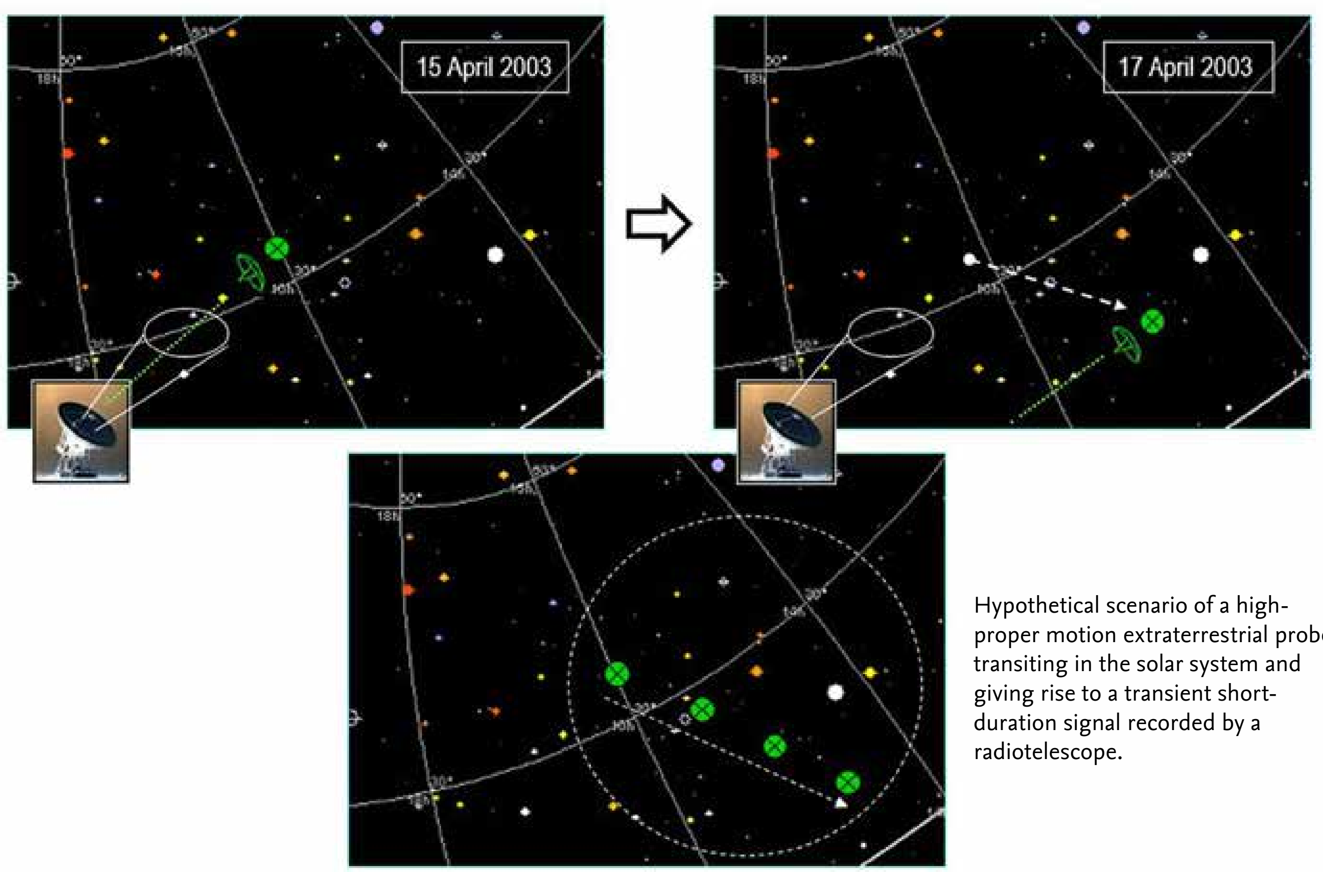


Expected infrared excess from Dyson spheres (left) and simulation of an anomalous light curve (right, Arnold 2005).

using both normal telescopes connected to photon-counting detectors characterized by very high temporal resolution, and infrared space telescopes such as the James Webb currently in orbit. These are very sophisticated, rigorous, technically ready, and highly feasible research projects. In a further phase, the search for possible technosignatures from solar-type stars would be used as an optimum "viewfinder" in order to address standard SETI research in a more targeted way, i.e., the search for intelligent signals coming from stars that show the signs of extraterrestrial technology in their circumstellar space (Teodorani, 2014a).

Interstellar Migration

Astrophysics—in particular, the theory of stellar evolution — tells us that stars like ours, where life could exist, can last at least one billion years. This is the time taken by hydrogen to burn thermonuclearly inside them until completely consumed and before expanding into the red giant phase. Some planets that happen to orbit around these stars, mainly of G spectral type, could have had plenty of time, not only to generate life in its most complex forms but also to develop intelligence at extreme levels, up to the ability to build up unimaginable technologies, such as those able to allow these intelligences to roam undisturbed in the galaxy and perhaps beyond. In essence, some intelligences may have gained the capability to migrate anywhere (Deardorff, 2005; Finney, 1985; Jones, 1981; Newman et al., 1981). At this point, the Drake equation should be enriched by one more multiplicative parameter: the migration parameter (Walters et al., 1980). This parameter would increase by at least one million times the number of existent, intelligent civilizations in the galaxy, which presumably would stay for relatively short times on colonized planets, spending most of their time traveling in space. In fact, specific calculations based on the so-called "diffusion equations" prove that the colonization process carried out by advanced extraterrestrial civilizations would manifest as a migratory flux similar to a real "wave" with a growth rate of one-thousandth of light-years per year. In this way, the entire galaxy could be entirely colonized in a period of the order of 60 million years, or in a time that is at least 150 times less than the age of the galaxy itself. Therefore, not only does there exist plenty of time to colonize the galaxy and, therefore, the planets of our solar system, including the Earth, but the visits that interest us—i.e., those on planet Earth—could have already occurred at least 10,000 times over the last 2000 years. Obviously, there is still no scientific evidence that all



Hypothetical scenario of a high-proper motion extraterrestrial probe transiting in the solar system and giving rise to a transient short-duration signal recorded by a radiotelescope.

this has actually happened, but there are some factors that stimulate us to consider this research worthy.

Regarding the possibility of interstellar migration, there are new ongoing projects intending to verify the presence of any alien probes within the solar system, near the Earth itself, and inside its atmosphere. This was born about twenty years ago with the denomination of SETV (Search for Extraterrestrial Visitation) (Stride, 2001), and it continues with the more developed *Galileo Project* led by Harvard astrophysicist Avi Loeb. According to the SETV strategy, the entire solar system would be meticulously monitored using wide-field monitoring systems such as PAN-STARRS, optical and infrared telescopes, and also radio telescopes used both as receivers and as large radars, in order to detect the possible presence and/or transit of robotic probes or large mobile space stations called "Dyson arcs," hypothesized a few decades ago by physicist Freeman Dyson. These arcs are hypothesized to be pieces of a preexistent swarm coming from a Dyson sphere originally surrounding a star engineered by very intelligent beings and put in motion towards interstellar space for a purpose, such as the possible escape from the expanding envelope of a star that is becoming a red giant.

…peculiar light curves and infrared excess from stars of a solar spectral type—can be studied using both normal telescopes connected to photon-counting detectors characterized by very high temporal resolution, and infrared space telescopes such as the James Webb currently in orbit.

It is expected that possible objects inside the solar system possess a very high proper motion and a strong infrared signature (Teodorani, 2014b). Obviously, we already know which peculiar signatures they would show, especially if compared with the more common asteroids and comets—and in fact, due to this reason, specific astronomical instruments have already been chosen, including gamma-ray detectors from space. We know that some space civilizations visiting the solar system could also use matter-antimatter annihilation as a propulsion system—in addition to sails driven by the radiation pressure, which might emit sudden gamma-ray bursts within or just outside the solar system (Harris, 1986).

Something of these interstellar intruders might have been already discovered by chance with the Oumuamua object a few years ago (Shmuel & Loeb, 2018), and a systematic project in order to discover these kinds of objects in the future is currently being prepared by a very specific branch of the Galileo Project.

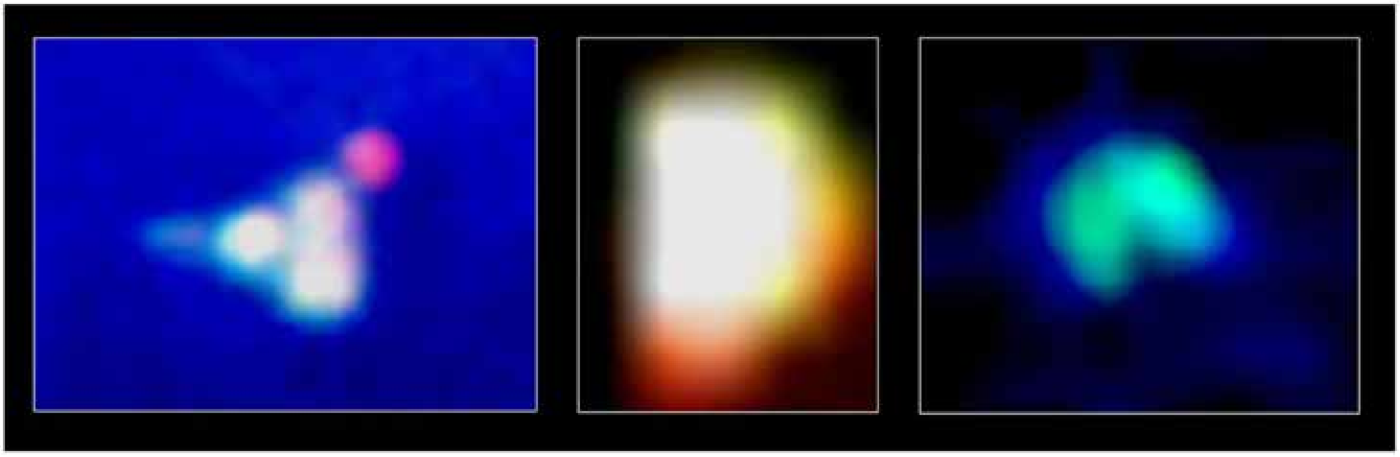
Anomalous "stars" that appear and vanish from sky maps in a matter of a few hours are not easily interpreted as transient phenomena in some kind of known "variable stars," and must be investigated further (Villarroel et al., 2022). Analogously, fast extremely intense outbursts of energy emitted in the radio band, such as the FRBs (Fast Radio Bursts) so far cannot find a clear and definitive explanation in terms of known astrophysical phenomena such as magnetars or black holes (Lingam & Loeb, 2017).

Destination Earth?

If galactic civilizations that are far more advanced than ours are able to move from one star to another, they might be able to visit the Earth, too (Loeb, 2021). Anomalous phenomena, or "UAP" (Unidentified Anomalous Phenomena), reported in our atmosphere might be a signature of such visitations. This is another important branch of the *Galileo Project* (Watters et al., 2022). Which of these phenomena are due to natural or manmade causes, and which ones are not? In all cases, we would have something important to learn, also in the field of fundamental physics.

Anomalous phenomena in the Earth's sky have shown several behaviors, ranging from so-called "nocturnal lights" to apparently structured crafts (Hynek, 1972) that cannot be identified with known technology, and which often show kinematic and light emission characteristics that are unusual and apparently not explainable by known physics laws (Maccabee, 1999; Knuth et al., 2019; Teodorani, 2004; Vallee, 1998). Most of these manifestations can be identified as misinterpretations of known manmade and natural phenomena (Condon, 1969; Pettigrew, 2003) or as mere hoaxes, especially in this era in which CGI technology can create fake movies and photos. Independently from this and so far, witnesses are the main "data" that can be evaluated. Unless we have at our disposal an overpopulated database with which acceptable statistics can be built up, human testimony of anomalous phenomena—although interesting per se for human and social sciences—cannot be used as evidential proof for physical science.

If we suppose that the Earth is visited by intelligent extraterrestrial beings, we should expect to see possibly transient anomalies in our atmosphere that have a technological signature and behavior, especially in terms of speed, luminosity and morphology, that cannot be produced by human technology (Teodorani, 2000). The difficult task



Some of the light phenomena recorded by the author in Hessdalen.

here is to distinguish very carefully which ones of these anomalies are of natural origin (Brovetto & Maxia, 1995; Freund, 2003; Smirnov, 1994; Stenhoff, 1999; Zou, 1995), which ones are a product of advanced terrestrial technology, and which ones cannot be identified with the first two categories. Once the third category is suspected to be the result of an exogenous visitation, the next task consists of trying to understand how this category works in terms of the known laws of physics. This involves the investigation of possible propulsion systems (Meessen, 2012), which might be identified from the radiative processes in a wide range of wavelengths, and the investigation of how such devices are intelligently driven. For instance, the capability to identify a Zeeman effect in the spectral lines of a luminous object at night would allow us to measure the magnetic field within the produced plasma and the way in which its intensity varies with speed, optical and infrared luminosity, color, radar signature, radio emission, and sound. In such a way, crucial physical information could be inferred from the effects produced by some kind of propulsion mechanism.

It is generally expected that such hypothesized intrusions in our atmosphere occur transiently and randomly on Earth, so these occurrences cannot be predicted in order to allow researchers to be prepared with sensing instrumentation. In such a case, instrumented scientific investigations would not be possible. Instead, in order to do science on this kind of investigation, it is necessary to acquire physical data using well-calibrated multimode and multi-wavelength measurement sensors, through which the signals of interest and the related measurement errors can be accurately evaluated.

Fortunately, in addition to the transient occurrence of anomalous events on Earth, there is also strong evidence that in some areas of Earth, atmospheric anomalies occur with remarkable regularity (Rutledge, 1982). Such locations can be suitably chosen as the best sites for scientific

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monitoring in order to ascertain the nature of the phenomenon, including a possible extraterrestrial origin too. For instance, this has happened since 1984 in the area of Hessdalen in Norway, where up to ten sightings per square kilometer in a radius of about 5 Km have been reported every year. In this specific location, research has been carried out using measurement instrumentation (Teodorani, 2004). So far, the results of this scientific investigation do not show that "Earth is being visited," but rather prominent anomalies in the behavior manifested by the observed phenomenon. Hessdalen is not the only world location of interest regarding recurring anomalous phenomena; for instance, areas such as Catalina Island, the Yakima reservation, Brown Mountain, the Hudson Valley, the Uintah Basin, Piedmont, and Marfa in the United States are worthy of investigation.

One fundamental goal of this research is aimed at trying to understand the physics of the observed phenomena, especially the confinement mechanism of plasma, which manifests as "nocturnal lights" characterized by strong light and color variability, sudden multiplicity, unusual kinematic behavior, and often by electromagnetic interference

(Rodeghier, 1981). Sometimes plasma-like "light balls" overlap with the transient apparition of apparently-structured objects: the reason for this connection is not known yet, but it must be investigated in-depth.

Whatever the phenomenon is, identifying the physical mechanism is, without a doubt, our main goal, even if what is observed gives the impression of sometimes defying the laws of physics themselves. We can investigate all of this using exactly the same posture that we use in astrophysics and the standard methodology of science. The correct approach is to maintain an aseptic equidistance from both hypotheses: natural or non-natural. Physics is the only real issue that matters here, whatever the nature of the phenomenon may be.

The key to unveiling the physics of what is observed in the skies of the world consists not only in measured "static characteristics" such as spectra, CCD images, or luminosity distribution but, above all, in the phenomenon's time variability within a wide range of wavelengths. Just this second approach allowed us to understand the physical mechanism that is working in celestial objects such as Cepheid stars, quasars, accretion disks, close binary stars, pulsars, gamma-ray bursts, or star spots. The ways in which physical parameters vary with time were able to tell us much of what we already know in astrophysics, namely the dynamics of celestial objects. This same procedural philosophy can also be applied to UAP, especially nocturnal lights. Multiwavelength observations of strongly varying phenomena, kinematically, photometrically, and electromagnetically, using properly calibrated instruments, can allow us to understand the physical mechanism on which such phenomena are based. This means acquiring data, in 24h and automatic mode (Watters et al., 2022).

The interpretation of these dynamics can help us to understand quantitatively what is going on by subjecting such data to mathematical modeling. This is exactly what we do in astrophysics. An aseptic and agnostic aptitude, which is what science actually is, can tell us if what comes out from the data is the result of a natural phenomenon, a mere misinterpretation of known natural or manmade phenomena, or a propulsion mechanism that is not known to us yet. This can come out only from the measured data, not from preconceived belief systems of whatever nature. This is in the name of Galileo, which should always be alive in the mind of physical scientists.

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