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From Copernicus to the Edge of the Universe

Abstract

The article comments succinctly on the expansion of boundaries of scientific knowledge: from the Solar System of Copernicus to the contemporary, precise investigation of the frontiers of the Universe via measurements of cosmic microwave background radiation, as well as direct exploration of the Solar System, as, for example, with the robotic missions to Mars. The phenomenal progress of astronomy, physics, and, in general, the knowledge of the Universe since the Copernican initiation of the contemporary scientific revolution has nevertheless, in the author's opinion, left us awaiting "The Modern Copernicus", who, hopefully, will be once again able to chart a course to a true, complete understanding of the Universe which surrounds us.

Five hundred years after the revolution that unseated Earth from the center of the cosmos, humanity is reaching with its understanding toward the very edges of the Universe. But has half a millennium of scientific progress, the refinement of our cognitive tools, and our ascent to a decidedly higher civilizational level brought us any closer to the ultimate truth about the Universe? Or, to ask provocatively: are we, nevertheless, still in a position much like those of the many generations since the time of Copernicus? We are, after all, making breakthrough discoveries that define our place in the Universe. Yet are we, perhaps, just as lost and uncertain as the people of the 16th century? What do Copernicus's breakthroughs mean in this context? Is their value even measurable, and can we today, like those before us, redefine our existence based on science and our vastly expanded knowledge?

A Flash of Genius on the Frontiers of the World

In 1543, in the small town of Frombork in Warmia, a canon by the name of Nicolaus Copernicus was dying. This place – remote even today, and at the time removed even farther from the metropolitan core – paradoxically proved to be the center of a colossal scientific breakthrough. On his deathbed, Copernicus lived to see the first printing of his life's work, De revolutionibus orbium coelestium. The book had sat in a drawer for nearly four decades; latest research by Prof. Leszek Satora from Kraków suggests that the first seeds of heliocentric thought (Copernicus's so-called Commentariolus) were sown as early as 1507 in Lidzbark Warmiński. What was heresy or, at best, a mathematical curiosity to his contemporaries, turned out to be an intellectual breakthrough of unceasing significance. Copernicus formulated what we now call the Cosmological Principle, or, in full, the Copernican Principle of Mediocrity: as inhabitants of Earth, we do not reside in a privileged place in the Universe – on the contrary, we occupy a statistically average point in space.

Today, this truth is so self-evident that it defines the context for both our existence and scientific methodology. It does not terrify us; rather, it gives us the strength and determination to continue our search – to fight for knowledge-based truth. In the 16th century, it was the

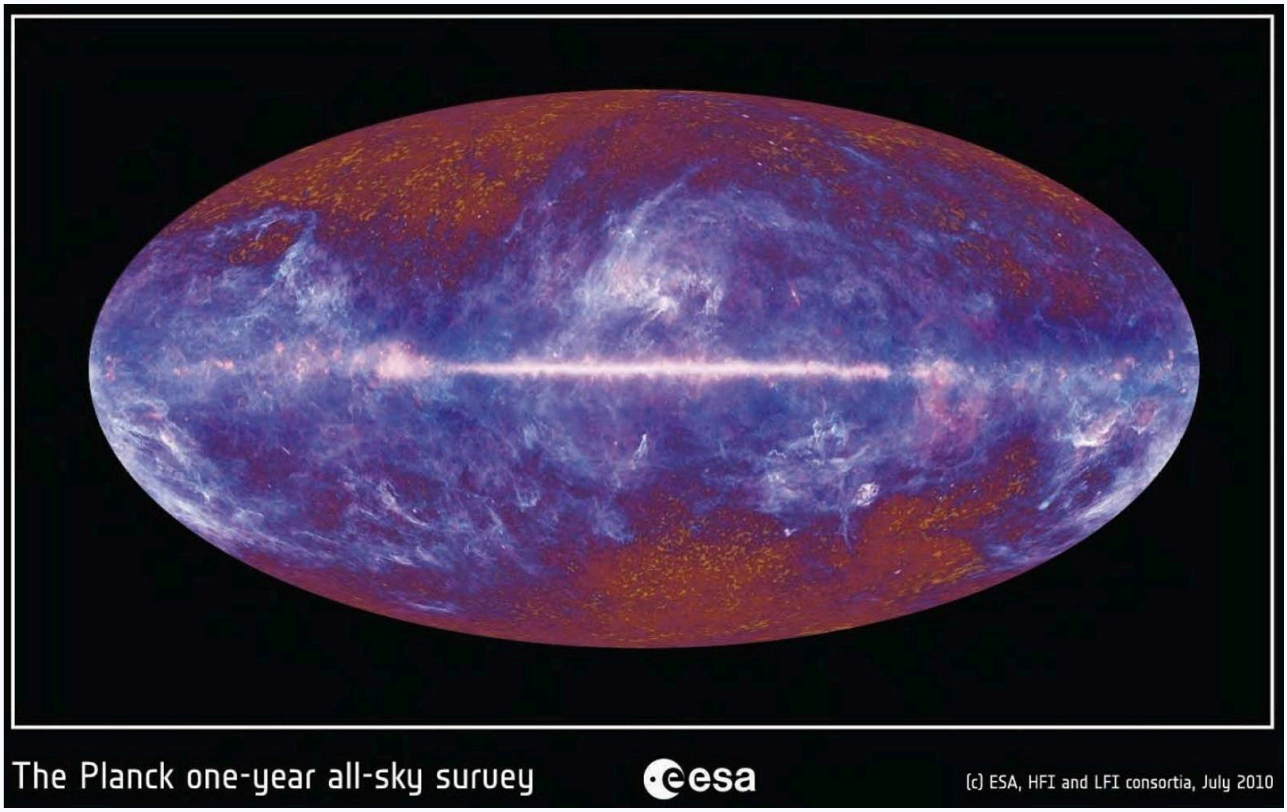
upheaval which established that Earth is not the center of the Solar System – that the Sun takes that central position. In 2026, this implies something far more radical.

From Six Thousand Stars to 14 Billion Light-Years

When Copernicus looked at the sky with the naked eye, he saw about 6,000 fixed stars, five "wandering" planets, and the occasional fear-instilling comet. He did not use a telescope (which had not been invented until 65 years after his death), he did not know the law of universal gravitation outlined by Newton (b. 1643; d. 1727), and he certainly had no access to spectroscopy, photography, or satellites; in his day, the term "computer" referred simply to people specializing in mathematical calculations. Today, in an era of ongoing revolutionary development in astronomical instrumentation, we observe phenomena whose existence in the Universe had not even been suspected until the 20th century.

The all-sky map of microwave radiation produced by the ESA's Planck satellite mission (specifically, its data from 2009 to 2013) reveals three simultaneous layers of cosmic reality. The equatorial white streak is our Galaxy, the Milky Way – the full nature of which humanity only began to grasp at the end of the 19th century. The mixture of mottled orange and red spots illustrates temperature fluctuations in the Cosmic Microwave Background (CMB) – the oldest observable light in the Universe, which has been traveling towards us for approximately 13.8 billion years, effectively since the Big Bang. In these CMB observations, we see the Universe at a mere 380,000 years of age: hot, nearly perfectly homogeneous, with microscopic density fluctuations that would later become astronomical objects – superclusters, clusters of galaxies, and galaxies themselves, with the entire "cosmic zoo" of objects they contain.

Everything between our Galaxy and the frontiers of the observable Universe seen in the background radiation consists of myriad of galaxies, quasars, and clusters, separated by



Ilustracja 1. The Planck all-sky one-year survey.

gigantic empty spaces also known as voids. Together, they form the so-called Large-Scale Structure of the Universe.

We are all residents at the bottom corner of this map – at a tiny, local point in our Galaxy. We are in the exact same spot we were five centuries ago when Copernicus, on his deathbed, leafed through his *magnum opus*. What is new? Namely, that today we see this place more clearly, we can define our surroundings more precisely, and we understand much better the physical processes that shaped our current astronomical environment. But do we know "everything" yet? Do we have the complete answer to the fundamental questions of astronomy?

The Copernican Principle has been extended to the limits of our imagination: not only is Earth not at the center of the Universe, but there is, in fact, no center at all. On the largest scales, the Universe looks (statistically speaking) the same in all directions and likely in all places (i.e., it is isotropic and homogeneous). These statements are no longer mere philosophical declarations – they are empirical facts of modern cosmology, established through astronomical measurements with a precision higher than one part per million.

A Precision That Unsettles

Over the last 100 years, cosmology has moved from speculation to a science of unimaginable rigor. The Standard Cosmological Model, known as the Lambda Cold Dark Matter model (Lambda-CDM), describes observations with an accuracy that was, until recently, unthinkable. We know the age of the Universe is over 13 billion years. We have measured the rate of the Universe's expansion (the Hubble Constant): 67–74 km/s/Mpc, where both of these quoted values are derived from different astronomical observations. These, according to their proponents – carry such small measurement errors (approx. 1–2%) that they are, in fact, in conflict with one another – one which still awaits resolution (better measurements? or perhaps the need for "new physics"?).

We also make estimations of the composition of the Universe: ordinary baryonic matter (the matter we know from everyday life or laboratories) makes up only ~4.9%, Dark Matter ~26%, and Dark Energy ~69%.

And it is precisely here that a problem emerges – one that will likely prove to be the "threshold of the next Copernican revolution." We possess a mathematical model, the aforementioned Lambda-CDM, which, despite its "simplicity," works remarkably well in describing the evolution of the Universe. However, it does require the existence of two unknown components for which we have no acceptable explanation within the framework of known theoretical or experimental physics. (One might be reminded here of pre-Copernican, Ptolemaic epicycles – those "ghostly" circles necessary to explain anomalies in the observed orbits of planets...)

Thus, Dark Matter – essential for gravitationally explaining the movement of galaxies but invisible to electromagnetic radiation – and Dark Energy – even more mysterious, manifesting itself primarily through the accelerated expansion of the Universe – defy our intuitions and thoroughly test our current view of the physical world.

Of course, the Lambda-CDM model does not perfectly describe all astronomically perceived reality. For instance, the James Webb Space Telescope has already discovered galaxies so massive and so old (physically evolved despite existing only 300–500 million years after the Big Bang) that, according to the Lambda-CDM model, they should not exist at all. There simply has not been enough time to "produce" them. It currently seems that this is not a matter of a few "strange objects" awaiting a new interpretation, but rather a serious, systematic problem for the "standard" cosmological model. Perhaps – as history tends to proceed in cycles – we find ourselves in a pre-Copernican position with regards to the domain of cosmology, awaiting a new Kepler, a new Newton, or a new Copernicus.

From Warmia to Mars

Copernicus measured astronomical angles with a quadrant and kept time with a water clock. Today, the laboratory where the Polish astrophysicist presenting these slides has worked for over 20 years, builds robots that land on Mars. They arrive there at speeds of ~20,000 km/h, landing autonomously and softly (like the Perseverance rover in 2021). They fly in the thin Martian atmosphere (as did the helicopter Ingenuity – that made 72 flights instead of the 5 planned originally), and according to current plans, they may even bring Martian soil samples back to Earth (like the Mars sample-return mission, planned for the 2030s).

This is no longer the domain of mere observation; it is the active exploration of the Solar System. And while it is easy to admire the extraordinary progress of science, let us remember and respect that at the source of the modern scientific revolution remains that fundamental question asked 500 years ago on a tower in Warmia: "But what if it is the Sun that is at the center?" We believe that today's questions about dark matter or dark energy carry a similar intellectual weight and, once answered, will have a truly "Copernican" potential to revolutionize science and give it a new momentum for the next 500 years. Is that not a magnificent vision?

The Enigmatic Canon and the Cardinal Virtues

Copernicus remains a mysterious figure – not because we know little about him, but because (if we may indulge in some humor) he left no tweets, Instagram stories, or Facebook posts. We don't know what he ate for dinner, whom he argued with, or loved.

We know only what he contemplated – but that must suffice. In our age, so flooded with information, we can, however, attempt to connect with the cardinal virtues which anchored the man's life:

- **Prudence (*prudentia*)** – he had waited decades to publish his work until he was certain of the right moment to do so.
- **Justice (*iustitia*)** – he gave the truth to the world, even though he knew it would be inconvenient.
- **Fortitude (*fortitudo*)** – he courageously stood against the intellectual order of his time.
- **Temperance (*temperantia*)** – he lived modestly on the fringes of the world of his day.

In our times, so heavily influenced by social media, where many base their self-worth on "likes," the figure of Copernicus – undoubtedly a monumental national hero of Poland – should become a universal ethical model.

The Copernican Principle survived for 500 years now and proved to be far more universal than its author could have imagined. Earth is not at the center of the Solar System, the Solar System is not at the center of the Galaxy, the Galaxy is not at the center of the Universe, and the Universe has no center whatsoever. But perhaps we stand at a threshold where this principle will be tested once again – this time on a scale whereupon our current models cease to function. Perhaps the next Copernican revolution will discover that we are, in some sense, "special" after all – not in terms of place, but in terms of time; that we live exactly in the era in which we can seek ultimate answers. For, perhaps, that is how the legacy of Copernicus functions: it never ends – it is always just beginning.