

**TEN EQUATIONS TO
EXPLAIN THE MYSTERIES
OF MODERN ASTROPHYSICS**

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**FROM INFORMATION AND CHAOS THEORY TO
GHOST PARTICLES AND GRAVITATIONAL WAVES**

Santhosh Mathew



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Ten Equations to Explain the Mysteries of Modern Astrophysics: From Information and Chaos Theory to Ghost Particles and Gravitational Waves

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Foreword

What if the reality that we see before us is only temporary? Or, perhaps it is not what we think it is. Where then do we look to grasp the essence of human existence? What if the concept of eternity is illusory? How then do we make sense of human existence? These are just a handful of the questions that Santhosh Mathew asks his readers to contemplate. These are not easy questions to answer, and when reading his book, it becomes clear that the answers to these questions are not likely to be found in many of the places where humans have typically searched for truth or have tried to garner deeper understanding. To further complicate our arrival at the truth, the noise and abundance of data that contemporary society drops on our lives diverts our ability to contemplate and understand our existence, and the world around us, with great clarity. Within Mathew's book, equations are the antidote that is suggested for the forces that stymie our understanding.

The questions posed above can be unsettling; however, Mathew acknowledges and welcomes the astonishment that accompanies the enduring quest among humans to find meaning.

As Mathew points out, humans strive to construct order from chaos in their lives through borders, systems, and tangible structures, yet all of these human ecosystems are fleeting since humans, themselves, are transient. This book, in focusing on the timeless qualities of equations, conveys both the joy of discovery and the possibilities that arise when one honors questions over answers, process over outcomes, and journeys over conclusions.

In order to thoughtfully explore such enduring questions, and to unravel select truths, Mathew suggests the importance of equations and shows readers that, due to their continual lifespans, equations offer us a link from the past to the present and into the future. Within his narrative, Mathew refers to equations as elegant, “timeless and spaceless” and can be, in the right hands, and contemplated through the right minds, a “beautiful painting hiding a message.” These descriptions present equations as invitations to connect moments of our history and discern the elements that underlie our existence. Through equations, we find not only a welcoming invitation but also deeply embedded meaning that has been formed and reformed throughout history, but not always well understood, and, at times, highly misunderstood.

While the book is structured to enlighten readers on ten questions, the prevailing themes are far from linear. Mathew weaves the present with the past; science with philosophy; and the spiritual teachings of religion with the discoveries of science. To further synthesize his themes, Mathew draws upon a wide range of writers, philosophers, scientists, and sources, including Herman Hesse, Carl Sagan, Franz Kafka, Stephen Hawking, Fritjof Capra, and the Bhagavad Gita.

Mathew takes a deep dive into each of the ten equations and illuminates how all of them hold basic truths. He artfully draws

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our attention to how equations connect to human behavior in the past, such as cave drawings by early man, to today's news-casts that construct narratives from disparate sources and define and redefine our contemporary social worlds. Other equations within the book's chapters demonstrate how everyday concepts, such as, what goes up, must come down, are used to enlighten our understanding of our wider world, sometimes with validity, sometimes with incomplete understanding, and sometimes even leading to popular misnomers.

At the heart of Mathew's book is the concept of entropy, derived from the Greek word *entropē*, meaning to turn toward or transform. While humans crave certainty, and often seek stability and absolute truths, Mathew shows his readers that far more can be learned through disorder, decay and chaos. Through entropy, a more nuanced truth and higher meaning emerge than could ever be realized through an existence predicated on certainty. Rather, through the lens that Mathew uses, probability offers far more potential than determinism. In many ways, Mathew's book invites its readers to become blissfully lost in novel findings, unexpected directions, and conclusions that guide explorers to a boundless array of unimagined pathways.

While Mathew presents equations as gateways to human understanding, the book illustrates that, throughout history, many humans have sought absolute truth, and even a sense of justice, through philosophical and spiritual texts. While Mathew does not dismiss the quest to understand life through a wide range of sources, this book shows how these sources simply illuminate and act as metaphors for the discoveries of science rather than supplanting science or serving in any way as equivalents.

Mathew's central message is that science is a journey rather than a destination. While humans may look at other sources

and crave singular explanations, or wish to place their trust in ancient texts, it becomes clear that these sources have limitations, at their best, and misguided notions at their worst, especially when used to support nationalism or other aggressive agendas. Mathew's book shows that human existence is dependent on continual discovery that only deepens and expands over time. Through this view, some of the worst enemies of the human race may very well be premature conclusions and easily arrived upon destinations since they may stifle the human quest for meaning. In essence, at the core of this book is the alluring and insatiable notion of curiosity. Through this lens, nothing is settled; therefore, everything remains possible.

Debra Leahy, Ed.D.
Chief Academic Officer, Boston, MA.

Preface

We all know transience is a part of life, but it is not just part of our life. Everything is transient, from the fundamental particles that make up every living thing to the ever-expanding universe—on a different time scale, though. We latch on to many things and ideas and assume they will remain forever, but eternity, whether on Earth or in heaven as some would like to believe, in a broader sense, is an illusion.

In his final novel, *The Glass Bead Game* for which he won the Nobel Prize for Literature in 1946, Hermann Hesse wrote:

No permanence is ours; we are a wave
That flows to fit whatever form it finds:
Through night or day, cathedral or the cave
We pass forever, craving form that binds.

The inspiration to present this work emerged from our transient human nature and the universe we inhabit. At the same time, we have a deep desire to discover the laws governing

everything around us, which I consider eternal. Our ancestors gazed in wonder at the world around them, just as we do today. They thought of the big questions, as we do even now. How did the universe begin? What is it made of? Where do human beings fit in this great cosmic scheme? Finally, is there a meaning to it all?

The meek and the powerful lived on this planet; so did the rich and the poor. Kings and emperors ruled the Earth, but they have all vanished and become part of the grand universe. What did they leave behind? We know that mighty structures can crumble without a trace, that species can become extinct and even their fossils may not be found in the long run, and in the far future, our planet may be gone. So, what will remain after we disappear? Definitely not any of the material objects we have created. Today's strongest structures can become fundamental particles of nature in the far future. We call this process natural decay. Yet, we can preserve something: the secrets we have unveiled about nature using our most rational tool called science. The most elegant way we can keep this information is in the form of equations.

The equations represent our intellectual ability to explore and find the irrefutable laws of nature and our insatiable curiosity to know more. We discover universal laws from patterns of nature we observe or data we collect, and this, in my view, is the greatest achievement of humankind. This human talent supersedes any other accomplishments, and so these equations represent an eternal state—they are timeless and spaceless.

No doubt humans will leave a lasting impression on the Earth's surface, or we may terraform other planets. We will play with mass and energy and create one form or the other, or we will travel to other parts of our galaxy on light sails. We may

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edit the genome to design a perfect species or send radio waves millions of light-years away, but none of these will stand the ultimate test of time. Nature will be able to wipe out all signs of human existence on Earth or any other place we occupy.

As humans, we embrace specific beliefs and often imprison ourselves within the culture that we create and are proud of. We create borders and language, all with the hope of having some control over our surrounding world, and then we realize the inevitable futility of those controls. We need something in which to trust permanently, and we call it eternal. It is unimaginable for us to spend our lives in a random universe without any specific purpose and to leave things beyond our control. That will bring only despair.

I believe equations are the only way to know the universe even if we are not close to presenting a definite answer to many perplexing questions. The equations are not mere symbols with abstract meaning; rather they are like beautiful pieces of artwork that capture the essence of nature. Like a beautiful painting hiding a message, the equations unveil the mysteries of our nature and the process of knowing. That is the most wonderful experience! These equations represent absolute laws of nature, and they do not provide us with many choices. We must simply obey.

Despite all the fascination surrounding these equations, I must caution you that nature and the laws of nature are not fine-tuned for humans. We are a transient species that happened to find ourselves here on this tiny planet about a quarter million years ago. As Carl Sagan noted, “The universe is not required to be in perfect harmony with human ambition.” Yet, our voyage continues.

In the coming chapters, you will see ten equations that will outlast even the most enduring signs of our civilization.

Ten equations to explain the mysteries of modern astrophysics

These equations have changed the way we live and view the world and will continue to do so. They have the potential to take us from planet to planet and perhaps to make us a cosmic species or to destroy the last strand of DNA. I hope that you enjoy the experience of knowing these ten equations closely (some are well known mathematically) and that you develop an appreciation for them. They are intangible but can create a tangible world; nevertheless, they remain truly eternal.

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Santhosh Mathew

Introduction: the origin of equations

It has been said that humans, and all that comes of humans, fades, and so do any living things that spring from them. Nevertheless, if there were something that defied this rule, it would be those equations that humans invented and that serve as a tremendous resource to comprehend and appreciate the complex universe in which we live. Moreover, those equations have the potential to create a new world, maintain our own world, or destroy the world. They are visible everywhere—from battlefields to graveyards, from the heart of a flower to the core of a galaxy. We, the transient humans, continue to search for these eternal equations, and they provide a timeless experience in this ever-changing universe. There is no time and space in the world of equations as they transcend even the boundaries set by human imagination. Moreover, they inspire us to embark on a journey to comprehend the magnificent universe and its workings.

This book introduces ten equations that unravel the mysteries of our universe, and I hope it will take readers on a journey

of self-discovery where they will learn history, science, and the significance of these equations in their lives in addition to the mathematical beauty of these equations.

What is so remarkable about equations? They have a universal beauty attached to them that transcends earthly borders. Moreover, they do not have an aspect that we associate with other things, (e.g., cultures, geographic locations, or nationalities). The equations are truly universal. It is no wonder Galileo said, “Mathematics is the language in which God has written the universe.” Needless to say, it is quite natural to use mathematics to express the laws of nature in an elegant way.

Look at any product or social construct we deal with. All carry baggage associated with nationality and often relish those attachments, but the equations transcend those man-made systems. Using pictures and symbols, the ancient Babylonians and Greeks tried to explain relationships between different things. These bits and pieces set the stage for equations to appear in the human world. Essentially, the idea behind equations was the desire to connect seemingly different things with a common thread. Later on, these threads were woven into the fabric of the modern world that we live in—from electricity to the internet, from atoms to artificial intelligence, from cannonballs to rockets, and the list goes on.

This idea of interconnectedness and exploration is so fundamental to human existence that it is unlikely to vanish from the human psyche. In fact, today’s world of networked systems exhibits another example of this deep-rooted desire to be connected. Long before any modern systems were even imagined, our ancestors displayed the same intention as we do now.

The equations come in myriad forms and are packed with symbols and notations that seem abstract, but they enrich our

daily lives in various ways as you will see in the coming chapters that introduce ten different equations, which are also tied to various astrophysical phenomena. I have to admit that, even when some of these equations seem quite familiar, we do not fully understand their depth, although we use them in various forms—a humbling reason why we should continue to learn more about equations that connect everything in our universe.

The current form of equations, identified by the equals sign ($=$), appeared for the first time in the sixteenth century. That symbol, now universally accepted by mathematics as the symbol for equality, was first recorded by Welsh mathematician Robert Recorde in *The Whetstone of Witte* in 1557. In his book, Recorde explained his design of the “Gemowe lines” (meaning *twin* lines, from the Latin *gemellus*). The first-ever equation with the now common equals sign, $14x+15=71$ in modern terms, was mentioned in his book. With the publication of this book, Recorde is credited with introducing algebra with a systematic notation to England.

The equations are not merely symbols and variables, as they seem to be. In fact, they combine everything we know about our universe and provide a deeper understanding about our natural world. They are the ultimate manifestation of human ingenuity rooted in the laws of nature. In light of new evidence, we will abandon old ideas and theories and humans will depart the Earth, but the equations will remain eternal.

CHAPTER 1

The equation that gave us a digital life

No theory of physics that deals only with physics will ever
explain physics.

—*John Wheeler, The Intellectual Digest (1973)*

Abstract

On a fundamental level, what is our universe made of? Space, time, matter, and energy—those are all familiar explanations. However, some physicists propose that information is the fundamental ingredient of our universe, not force fields or space-time as generally accepted now. Therefore, if information is so fundamental and essential to this universe, the equation that launched the information revolution must be considered, not only in communications, but also in the fundamental understanding of this universe. The idea of the holographic principle makes more sense if we can link it to information theory. This chapter explores the significance of the Shannon

equation in the context of the holographic principle, a radical idea in modern astrophysics.

The idea that the information exchange among physical processes could be the foundation of this universe, though it sounds strange, is not very hard to understand. Imagine a computer, which is essentially an information-processing machine. However, without the software to run it, it is merely pieces of metal and glass. Alternatively, think about the actions that should happen in our body cells. We cannot even picture them without the information from DNA. So, we could say with a greater degree of confidence that, in the absence of information, objects are not what they seem to us. It is such simple logic.

Similarly, the universe that we live in and observe could be considered as a huge system operating with information as the underpinning factor. Proponents of the holographic principle say that we should explore this aspect to know the fundamental truth. Some theorists argue that to marry quantum mechanics with gravity requires this radical approach that put information at the core of this universe and that information is much more significant than space-time or matter and energy.

Generally, physics describes the fabric of our universe as space-time where the interplay between matter and energy embodies everything in this universe. In addition, the general theory of relativity says that, at its most basic level, this fabric should be smooth and continuous. Yet, if we examine the fabric of space-time on a fundamental level, it is not continuous, as we might imagine, but simply grainy. These grains act like dots in an image providing us with the vision of a three-dimensional universe. This idea led to the so-called holographic principle proposed by Nobel-Prize-winning Dutch theoretical physicist Gerard 't Hooft (1993). The evidence to support this

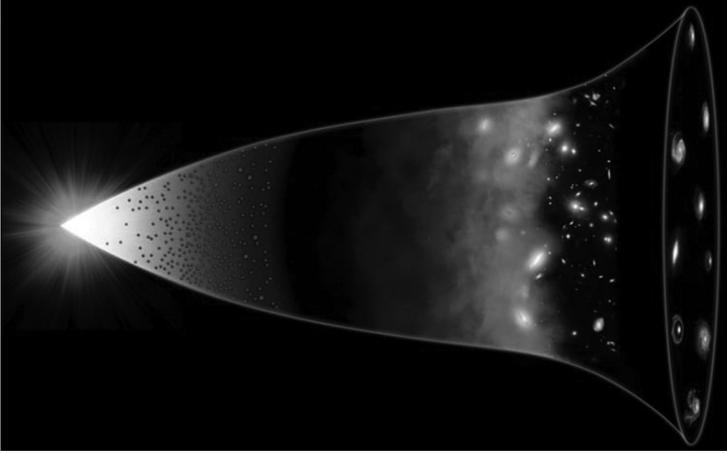


Fig. 1.1. *The universe is shaped like a giant bell lying on its side. The bell was struck nearly 14 billion years ago and emerged in oscillating waves from the singularity. Is our universe simply made of information? Image courtesy of the Perimeter Institute, Waterloo, Ontario, Canada.*

principle came from the irregularities in the cosmic microwave background, popularly known as the afterglow of the Big Bang. According to the holographic principle, our world is simply an image of the information stored on a two-dimensional projection similar to a holographic image (Fig. 1.1). The holographic principle tells us that when we look at this two-dimensional projection the right way, it gives us the view of a three-dimensional universe. In simple terms, our 3D world is a mere gift from the underlying information. Although not every physicist buys into this argument, it received considerable attention from the physics community.

In the 1980s, even before this holographic picture of our universe was presented by researchers, the legendary physicist, John Wheeler, hinted at the significance of information in understanding our cosmos. He described his evolution in physics as