FROM THE HEART OF THE STATE

The Governorate tells its Story

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THE VATICAN OBSERVATORY: A DIALOGUE BETWEEN SCIENCE AND FAITH

Dedicating an issue of this newsletter to the Vatican Observatory is an invitation to discover a reality that is often not well known. The Observatory is a scientific institution linked to the Vatican Governorate that provides scientific expertise, in the service of the Pope. Its origins date back to 1578, when Pope Gregory XIII commissioned the construction of the astronomical observatory - the Tower of Winds - and invited the renowned Jesuit astronomers and mathematicians of the Roman College to prepare the calendar reform, promulgated in 1582, known as the Gregorian calendar.

Undoubtedly one of the oldest astronomical observatories in the world, after a forced closure by the forces of the Risorgimento, it was re-established in 1891 by Pope Leo XIII, confirming the Church's commitment to promoting scientific research and fostering dialogue between faith and science.

Indeed, over the centuries, the desire to develop a scientific institution dedicated to observing the sky and deepening knowledge of the Universe led to the installation of important scientific instrumentation within Vatican territory.

With the expansion of Rome's urbanization and increased city lighting, in 1935 the Vatican Observatory was moved outside Rome to the Pontifical Villas in Castel Gandolfo, where the conditions for astronomical observation were more favorable. As light pollution increased over time, the need for an even more suitable location became evident and in 1981 a second research center — the Vatican Observatory Research Group (VORG) — was opened in Tucson, Arizona. In 1993, in collaboration with the Steward Observatory, construction was completed on the Vatican Advanced Technology Telescope (VATT), which was installed on Mount Graham Arizona, the best astronomical site on the North American continent.

The Vatican Observatory is entrusted to the Society of Jesus – the Jesuits – whose astronomers from various countries around the world dedicate their scientific training to the research and study of galaxies and stars, as well as cosmology and the composition of meteorites. In addition to scientific research, the Observatory also plays an important educational and cultural role by organizing conferences, summer schools, and exchange programs with universities and international research centers.

For this reason, the Vatican Observatory is not merely an observatory but a bridge between two dimensions: scientific research and spiritual reflection. In fact, the Observatory's astronomers not only study the Universe from a scientific perspective but also reflect on humanity's role in the cosmos.

In this sense, the Vatican Observatory represents a centuries-old tradition: that of a Church which, while safeguarding faith, looks with respect and objectivity upon the discoveries of science.

Nicola Gori
Editor

SCIENCE TOGETHER WITH CULTURE AND EDUCATION

The role of the Vatican Observatory in today's scientific and cultural landscape goes beyond simple astronomical observation. It represents a meeting place between science and faith. In an era where discoveries and scientific progress continue at an ever faster pace, the work of the Vatican Observatory bears witness to the importance of the Church's contribution to the advancement of knowledge. Moreover, astronomical research has always been inherently connected to the questions humanity has asked since the beginning of time: the origin of the Universe, its structure, the fate of stars and galaxies.

Faced with the immensity of the heavens, scientific reflection and theological reflection do not exclude one another, but can rather complement each other. In this sense, the Vatican Observatory does not seek to offer theological answers to scientific problems, nor use science to present the truths of faith. Its purpose is, above all, to promote openness, inquiry, and intellectual objectivity.

Another fundamental aspect of its role concerns its cultural and educational value. The Observatory has chosen to become part of the academic world by collaborating with universities across the globe to promote the training of young scholars and the spread of scientific culture. In this context, astronomy takes on the value of a universal language that transcends geographical, religious, and cultural boundaries.

Finally, the Vatican Observatory also serves a symbolic function. It reminds us that the search for truth is carried out through various forms, and that the desire to understand the Universe is part of the deepest vocation of the human being. Thus, gazing at the stars means recognizing the vastness of the cosmos and the limits of our knowledge, while also bearing witness to the extraordinary capacity of human intelligence in exploring the infinite.

For this reason, the Vatican Observatory continues to be a place where science is regarded not as a rival to faith, but as one path through which humanity seeks to understand the mystery of the Universe.

Sr. Raffaella Petrini
President of the Governorate of Vatican City State

THE VATICAN OBSERVATORY: PROGRESS AND EVOLUTION

Fr. Richard D’Souza, SJ
Director, Vatican Observatory

The astronomical activity of the Holy See is not a historical exception, but rather the culmination of a centuries-old tradition whose roots lie in the Gregorian reform of the calendar. When Pope Leo XIII reestablished the Vatican Observatory in 1891 with the motu proprio *Ut mysticam*, his primary intention was to demonstrate “*that it may be clear to all that the Church and her Pastors do not oppose true and solid science, whether human or divine, but rather embrace it, encourage it, and promote it with every possible commitment.*” From the refinement of the ecclesiastical calendar in order to preserve the unity of the Church, the mission of the Observatory has today evolved: to show the world that science and faith advance together—by doing good science.

The history of the Observatory has been shaped by the need to preserve the integrity of scientific observations. Initially housed within the Vatican walls, it was transferred by Pope Pius XI to Castel Gandolfo in order to escape the increasingly intense lights of Rome. In 1935 the new site—equipped with two telescopes mounted on domes and a modern spectrochemical laboratory in the basement—was inaugurated by Pope Pius XI. Additional telescopes were built in the 1940s and 1960s within the Vatican Gardens, near Villa Barberini. By the 1970s it had become evident that the light pollution of Rome and the Castelli Romani was making telescopic observations increasingly difficult. In 1981, under the leadership of the then director Father George Coyne, the Observatory established a second site in Tucson, Arizona, and built a telescope in the same region, more precisely on Mount Graham. In 2009 the Vatican Observatory moved to the former convent of the Basilian Sisters, at the edge of the Vatican territory, near the main square of Albano Laziale. Today, from this new headquarters, astronomers can collect and process not only data from the telescope in Tucson, but also data from telescopes located at other remote and dark sites around the world.

The current operational structure of the Observatory, under the administration of the Governorate, is organized around four fundamental areas:

A) **Pure Research**: data analysis, peer-reviewed publications, and participation in international symposia.

B) **Interdisciplinary Dialogue**: promoting dialogue between theological thought and astrophysical discoveries.

C) **International Cooperation**: supporting astronomy in developing countries through the renowned biennial summer school and the McCarthy-Stoeger scholarship.

D) **Outreach and Advanced Education**: organizing scientific conferences at the facilities in Castel Gandolfo.

Since 1930, personnel management has been entrusted to the **Society of Jesus**, which ensures a combination of academic rigor and pastoral mission. The research staff—composed of fourteen Jesuit priests and brothers, divided between Castel Gandolfo and Tucson—covers a very wide spectrum of expertise. It is undeniable that there is a certain fascination with an observatory run by a community of priest-scientists, and it is precisely this that distinguishes the Vatican Observatory from other scientific organizations.

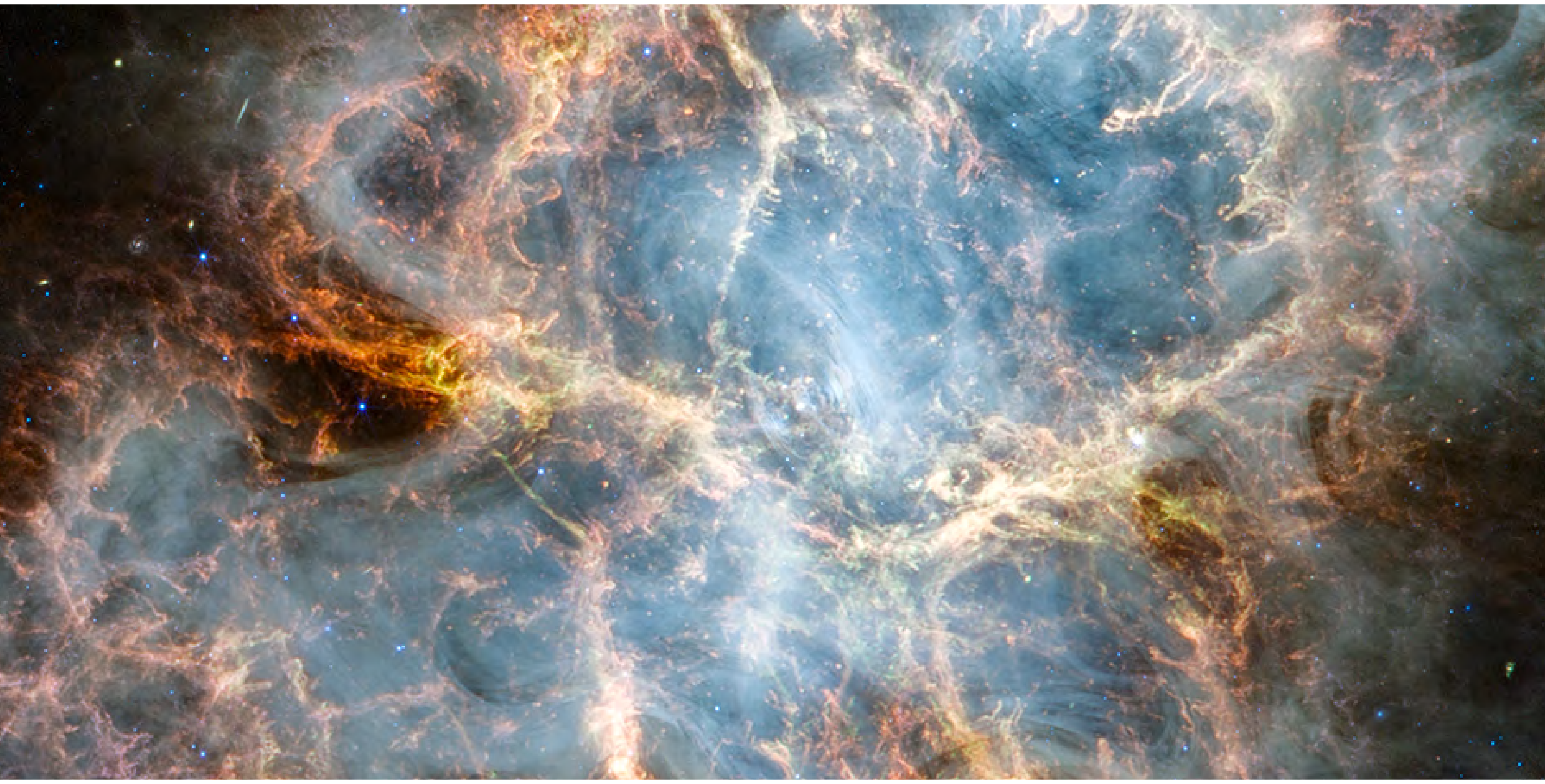
Needless to say, scientific research constitutes the basis and foundation of everything we do. It provides us with the authority necessary to engage in dialogue with astronomers and scientists. What is the Observatory currently working on? Beginning in the 1980s, the Observatory’s researchers began to diversify their research fields, each becoming an expert in a different area and thereby maximizing the presence of Jesuit astronomers across all branches of astronomy.

Father Gabriele Gionti, SJ, and **Don Matteo Galaverni** work on theoretical physics, studying the earliest phases of the Universe — the first moments after the Big Bang — and how traces of what occurred can be identified in observational data. **Don Alessandro Omizzolo** studies clusters of galaxies together with colleagues in Padua. I myself study the history and evolution of nearby galaxies similar in size to the Milky Way. **Father Richard Boyle, SJ**, at the age of 83, continues to carry out observations with our telescope in Arizona; together with **Father Robert Janusz, SJ**, he studies open clusters — that is, groups of young stars born together in our galaxy — in collaboration with a team from Vilnius University. Father Boyle, together with his collaborator, is also a prolific discoverer of new asteroids. **Father Chris Corbally, SJ**, is an expert in stellar spectra and their classification, continuing the legacy left by Father Angelo Secchi. **Father David Brown, SJ**, works with colleagues in Potsdam on the study of high-resolution stellar spectra. **Brother Guy Consolmagno, SJ**, and **Brother Bob Macke, SJ**, study the physical properties of meteorites — rocks originating from space. Their measurements help us understand the processes involved in the formation of our Solar System. Brother Macke participated in NASA's OSIRIS-REx mission, which visited an asteroid millions of kilometers away and returned samples to Earth that he helped analyze in the laboratory. **Father Jean-Baptiste Kikwaya, SJ**, studies the physical properties of meteors (or shooting stars) and asteroids in near-Earth orbit. **Father Paul Gabor, SJ**, is an expert in the history of astronomy. Finally, **Father Bayu Risanto, SJ**, has recently introduced the Observatory to the field of meteorology and to the study and forecasting of weather models.

Why is it important that the Vatican continue to maintain an observatory? Thanks to the breadth of fields it covers, the Vatican Observatory enjoys a high international reputation, not only for the quality of its research but also for the contribution it offers to the astronomical and scientific community. Our commitment within the International Astronomical Union is highly appreciated. Moreover, despite its small size and limited budget, the Observatory continues to bring a great deal of positive visibility to the Vatican: astronomical discoveries always fascinate the general public and quickly attract favorable media attention. The fact that the Vatican possesses a first-rate observatory and maintains a telescope at one of the best observing sites in the world clearly speaks to the Church's commitment to the sciences. Ultimately, maintaining an observatory of excellence is not only a cultural choice but also a powerful instrument of soft power. It communicates the Church's faithful commitment to the progress of human knowledge, reaffirming that the search for the laws governing the Universe is a path complementary to — and never opposed to — the search for the divine.

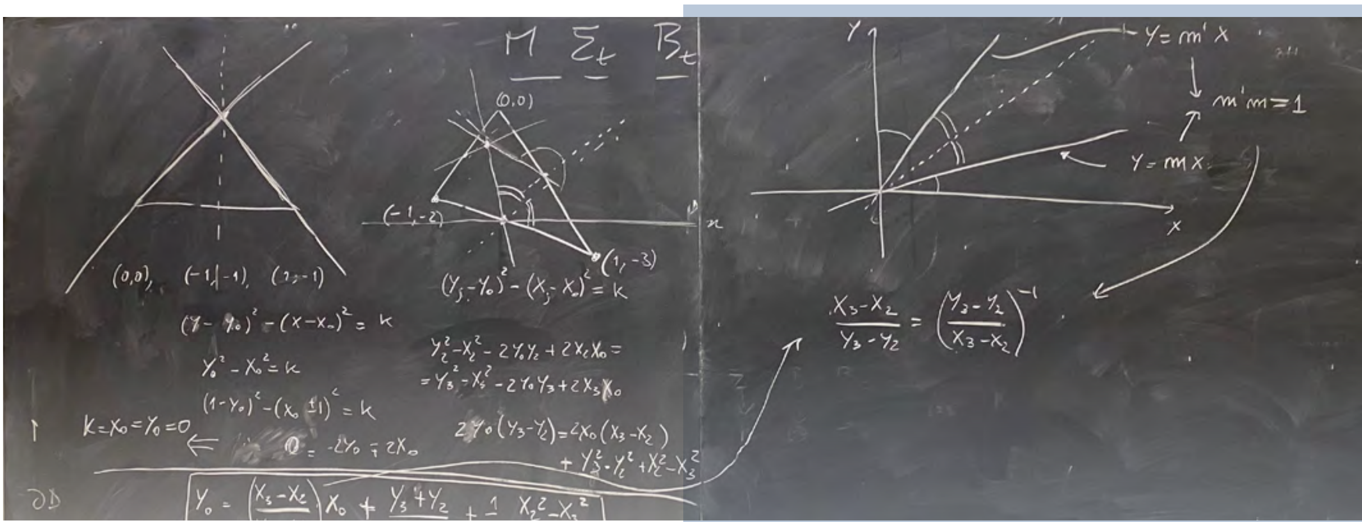
Today, the Observatory is in transition. After ten years at the helm, Brother Guy Consolmagno, SJ, has stepped down as Director. He will continue, however, as President of the *Vatican Observatory Foundation* in the United States, which is responsible for raising funds to support the maintenance of our telescope in Arizona. We are forming the next generation of Jesuit astronomers who will work at the Observatory, while also implementing strategic changes to adapt to the major transformations currently taking place in the astronomical community, where more and more experiments are conducted within large collaborations and surveys and where data are increasingly made freely available to the academic community.

These changes bring many challenges but also opportunities. Living on the front line of scientific research means evolving every day, learning new tasks and methods, and pushing human knowledge to its limits. In this way, we hope that through our lives dedicated to research we may continue to remain faithful to the mission entrusted to us by Pope Leo XIII: to show the world and the Church that faith and science can coexist.



AT THE ORIGINS OF THE UNIVERSE: THE VATICAN OBSERVATORY AT THE FRONTIER OF PHYSICS

Fr. Gabriele Gionti, SJ
Deputy Director of the Vatican Observatory



There is something in the Big Bang theory that modern science still cannot describe: the initial instant, an event located below the "Planck threshold," an extremely tiny interval of time between 0 and 10^{-44} seconds — that is, 0 followed by forty-four zeros before a non-zero digit. Imagine a universe compressed into an infinitely small point, dense and hot like an atom (as Msgr. Lemaître envisioned) or like the core of a star at the height of its explosion — so extreme that the laws of physics we use every day (such as Newton's gravity or Einstein's relativity) simply stop working. It is a "mathematical silence," a black hole of knowledge. It is precisely toward that point that our group of theoretical physicists at the Vatican Observatory is aiming.

1. Rewriting the Basic Rules of the Universe

The group works on **quantum gravity** — the dream of uniting quantum mechanics (which explains the microscopic world, such as atoms) with general relativity (which governs stars and galaxies). They use an approach called **discrete gravity**: space-time is not a smooth, continuous fabric but a mosaic made of discrete pieces, like the pixels of a screen or the Lego bricks of a castle.

The original idea dates back to the 1960s thanks to the Italian physicist Tullio Regge. Today it is being developed using advanced mathematics and powerful computers. At the heart of the problem lies Richard Feynman's "path integral." To predict how a quantum particle moves, one must sum all the possible trajectories it could have taken — not only the straight path but also curved and even absurd ones. Each trajectory has a mathematical "weight" (called the quantum measure), like a vote from 1 to 10. For gravity, this weight (technically the **Faddeev–Popov determinant**) had never been successfully derived. Within the scientific community this had generated a long-standing debate that remained unresolved, and numerical simulations produced unclear data.

The breakthrough comes from the "simplicial method with coordinates," created by Professor Alessandro D'Adda, who passed away in 2023 and supervised my own doctoral thesis. The idea is like organizing a chaotic puzzle: divide the universe into tiny triangles (simplices). Then assign coordinates arbitrarily to each vertex, identifying a reference system in each triangle. This first step is D'Adda's idea and still belongs to classical physics. I realized this idea could be implemented in the quantum world. For the weight of the Feynman integral one chooses only a class of reference frames in each triangle, the so-called **gauge fixing** (a trick to choose the right perspective, like rotating a map), and calculates the precise weight. The result? It becomes possible to simulate the zero instant of the Big Bang while respecting quantum rules and obtaining results that are no longer contradictory but internally consistent. An example: imagine predicting the weather — rather than a blurred cloud of uncertainty, you obtain a clear forecast.

2. Restoring Real Time

Another puzzle: to simplify calculations, many physicists treat time as if it were a fourth spatial dimension, using the **Euclidean metric**, where everything is positive, like distances on a map. It works for calculations, but it is not reality. Einstein taught us that space and time are different. In the **Minkowski signature**, space-time distances (space and time together) can be "negative" relative to purely spatial ones, whereas in Euclidean space they are always positive because time is treated as if it were spatial.

I think we can rebuild the entire theory of discrete gravity starting from this real physics, without shortcuts such as the **Wick rotation** — a mathematical maneuver often used to "correct" the Minkowski signature. In this approach, space-time intervals regain their proper nature: time-like (motion slower than the speed of light), space-like (distances that exist mathematically but would imply faster-than-light motion and thus have no physical meaning), light-like (distances traveled exactly at the speed of light). It is like moving from a flattened photograph to a fully interactive 3-D model: more complex to construct, but faithful to reality. Within the scientific community, building a discrete gravity theory with "real time" is considered the Holy Grail — solving it would change everything, like discovering the perfect recipe for cosmic bread.

3. Investigating Backwards Toward Hidden Theories

Together with the young Bologna master's student in theoretical physics Alberto Gavioli, with Fr. Matteo Galaverni, and with professors such as Alexander Kamenshchik and Sergio Cacciatori, we've adopted a detective-style method: **inverse reasoning**. Instead of starting with a theory and testing it ("if I use this recipe, what cake comes out?"), they begin with the already baked cake — the equations that explain the observed universe — and work backward to possible original recipes.

An explosive question arises: Are Einstein's laws of gravity the only ones possible, or do other theories exist that produce the same observable results but predict unexpected phenomena? This is not merely abstract. Ninety-five percent of the universe is "dark." Dark matter and dark energy are things we feel through their effects (for example, the acceleration of galaxies) but cannot see. Imagine a cake that rises in a strange way. Perhaps it is not caused by hidden yeast; perhaps the basic recipe itself is wrong. Dark matter and dark energy could be signs that gravity, as we currently know and describe it, must be corrected.

4. Changing Perspective Changes the Physics

Collaboration with Fr. Matteo Galaverni, Sergio Cacciatori, and Federico Scali (University of Como) has shaken a fundamental assumption about cosmic inflation—a phase of extremely rapid expansion immediately after the Big Bang, like a balloon inflated in an instant. Physicists often switch from the **Jordan frame** (where variables are complicated) to the **Einstein frame** (where they are simpler), assuming the physical results remain unchanged — like translating a book without altering its meaning.

They have shown that this is not always true. In some cases, the transformation changes the physics itself. It is a kind of earthquake: like discovering that rotating a map is not neutral but reveals entirely new roads. Now the research turns toward black holes, cosmic monsters that swallow everything. This "non-equivalence" could explain their **entropy** — the "disorder" that measures how information, originally ordered, becomes degraded and disordered because of physical processes occurring near a black hole. In this sense, the universe hides secrets from its very origins, like a vault secured by multiple codes.

A Science that Contemplates

From the Vatican Observatory emerges not only cutting-edge science but also a profound vision: studying the equations of the beginning of everything becomes an act of contemplation.There, where space and time merge, one brushes against the ultimate mystery. For scientists who are also priests, every equation uncovered does not distance them from God but rather illuminates the rational order of creation — like deciphering a divine symphony. Once again, reason and faith walk hand in hand.

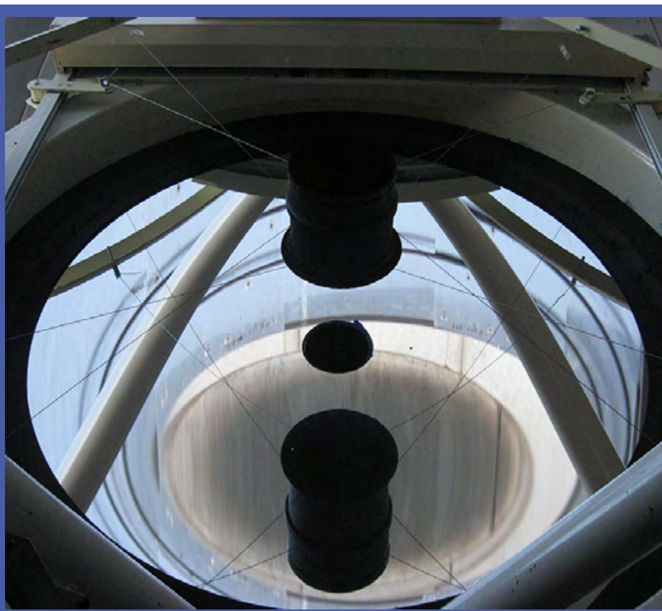
THE VATT:
THIRTY YEARS OF VATICAN ASTRONOMICAL EXCELLENCE

P. Chris Corbally, SJ
Vatican Observatory

Innovations in astronomy, cutting-edge instruments, and scientific research on Mount Graham

The Vatican Advanced Technology Telescope (VATT) has been the principal instrument of the Vatican Observatory over the past 30 years. It is located at an altitude of 3,200 meters on Mount Graham, in southern Arizona, about 110 km from the city of Tucson. The VATT is a joint project between the Vatican Observatory (75%) and the Steward Observatory of the University of Arizona (25%). The VATT's 1.8-meter mirror was fabricated at the Richard F. Carris Mirror Laboratory of the University of Arizona and was the first mirror produced using revolutionary technologies such as the rotating furnace and an internal honeycomb structure for rigidity. These methods are now routinely used to manufacture much larger mirrors of 8–10 meters. Thanks to the dry desert climate around Tucson, the high altitude of Mount Graham, and the constant commitment to preserving dark skies in this part of the world, the VATT is located at one of the best observing sites in the Northern Hemisphere. The VATT shares Mount Graham with two other telescopes: the Large Binocular Telescope (two 8-meter mirrors) and the Submillimeter Telescope. In addition, the mountains around Tucson host the largest concentration of telescopes in the continental United States, providing the observatory and the VATT with an exceptionally rich environment and infrastructure in which to operate.

How did the Vatican Observatory end up with a telescope in Arizona? Due to increasing light pollution around Castel Gandolfo outside Rome, Vatican astronomers began searching for a new location for their telescope. In the 1980s, the newly appointed director, Father George Coyne, sent a group of astronomers to form a small team at the University of Arizona, where they would have easy access to some of the best telescopes in the world by paying a modest annual fee. Meanwhile, Professor Roger Angel invented a new method for constructing telescope mirrors and tested a prototype mirror with a diameter of 1.8 meters, offering it to the Vatican Observatory. Father George Coyne was bold enough to accept the offer, on the condition that the Steward Observatory would continue to be involved. The subsequent and intensive fundraising campaigns, supported by both longtime and new generous friends, led to the naming of two major donors for the new facilities: the **Alice P. Lennon Telescope** and the **Thomas J. Bannan Astrophysics Center**. In addition, numerous donations and well-organized fundraising campaigns have helped improve and upgrade the telescope. Today, the telescope is funded thanks to the fundraising efforts of the Vatican Observatory Foundation and generous support from the Governorate of Vatican City State. Even given its relatively modest size, the VATT costs nearly half a million dollars per year to maintain: the main expenses are qualified personnel, infrastructure, and utilities required to operate a telescope in such an extreme environment.



Despite being 30 years old, the VATT is constantly evolving. A telescope is like a living being; it continually requires adjustments and upgrades. There are several reasons for this. First, electronics and mechanical systems have a limited lifespan, especially at high altitudes such as that of the VATT, and must be replaced and updated at regular intervals. Second, technological changes render many older systems obsolete but also introduce new technologies that allow better use of resources and facilities. Moreover, the usefulness of a telescope depends greatly on its instruments. Over the years, the telescope has hosted several temporary instruments. Today it has its own 4k CCD camera and an optical spectrograph (used to divide light into its constituent colors). As these instruments age, new installations are planned, allowing astronomers to conduct more innovative and creative experiments. The Observatory's astronomers have also worked hard to automate and robotize the VATT, making it fully automatic. This will allow more efficient use of the telescope: for example, several long-term monitoring programs of astronomical objects could be carried out each night, something that was previously impractical. A generous donation from the Thomas Lord Charitable Fund, together with a personal contribution from its president, Mrs. Judy Alstadt, made this possible. Since the beginning of the year, the VATT has been fully automated, and on September 29, 2025, the first fully remote VATT observing session was successfully tested. With this upgrade, the VATT begins its second life

Yet a fundamental question remains: what is the usefulness of the VATT in the era of space telescopes and 8-meter-class telescopes? The scientific niche of the VATT has always been the long-term monitoring and survey of astronomical objects, especially in the Northern Hemisphere. Given the high cost and limited availability of observing time, it is very difficult to obtain more than three days on larger or space-based telescopes. Long-term monitoring of peculiar stars or massive black holes can instead be conducted regularly with the VATT. Combined with a high-resolution spectrograph, the VATT excels at obtaining high-quality spectra of bright stars and quasars. Over the years, however, it has particularly distinguished itself in the discovery and characterization of asteroids, near-Earth objects, and trans-Neptunian bodies. Collaborations with numerous astronomical institutions have also shown that telescopes like the VATT are often ideal for testing new ideas and instrumentation before transferring them to larger facilities. From this follow two observations: a) the usefulness of the VATT increases greatly if it is opened to a broader astronomical community; b) the telescope becomes far more productive with newer instruments and a wider range of capabilities.

The VATT has also been an excellent telescope over the past 30 years for the training of young astronomers from universities in Arizona. Thanks to the generous donation of **Mrs. Kim Bepler**, this year the Observatory has launched a pilot program that offers 20% of its observing time to students from certain Jesuit universities in North America that lack the resources or access to a telescope for their research. Our hope is that one day the VATT will be available to universities around the world — especially in developing countries — to help train the next generation of astronomers.

As the Vatican's only active research telescope, the VATT has served — and continues to serve — as a powerful symbol of the Church's commitment to astronomy and the sciences. The fact that the Church operates one of the world's larger telescopes contributes more significantly to dialogues between science and religion than dozens of philosophical or academic articles on the subject. Beyond the many scientific results it has produced, the VATT stands as a symbolic beacon on a mountain peak, promoting the Observatory's mission "to show the world that faith and science can go together."

THE VATICAN METEORITE COLLECTION

Br. Bob Macke, SJ
Curator of the Vatican Observatory Meteorite Collection

Meteorites are time capsules that preserve information about the history and origins of our Solar System, and they possess enormous historical and scientific value

Although astronomers largely depend on the study of light (electromagnetic radiation) coming from very distant objects, planetary science offers some opportunities to get closer to the actual material itself. Space probes have visited planets and moons throughout the Solar System and, in a very few cases, have been able to recover material directly from these objects and bring it back to Earth for study. For example, the OSIRIS-REx mission recovered material from the asteroid (101266) Bennu and returned it to Earth to be studied by a collaboration of numerous institutions around the world, including members of the Vatican Observatory. However, these missions are extremely expensive and return only a small amount of material. On the other hand, we also have meteorites. These rocks, which have fallen to Earth from space, provide an abundant source of extraterrestrial material to study.

The Vatican Observatory houses a collection of 1,226 samples from 543 different meteorites. The origins of the collection date back to **Adrien-Charles Marquis de Mauroy** (1848–1927), an enthusiastic naturalist and collector of meteorites and mineral samples. In his time, he possessed the largest private meteorite collection in the world. He was also a devout Catholic and, during his lifetime, donated about 200 samples to the Vatican Observatory for study purposes. After his death, his widow donated the rest of the collection. In total, about 1,000 of our samples originally belonged to the Marquis's collection. The further growth of the collection has largely been due to the generous donations of other meteorite collectors over the past 100 years.

Since the Marquis mainly collected meteorites that were observed to fall — the identification and collection of meteorites that had remained on Earth for a long time was still in its infancy — the collection includes several meteorites of historical importance. Among these is *Ensisheim*, which fell in 1492 and was the first well-documented meteorite fall in Europe; and *L'Aigle*, which fell in 1803 and was documented and studied by members of the French Academy of Sciences, who demonstrated that meteorites came from space (rather than from volcanoes, as some had believed). The collection includes some very rare specimens, such as *Chassigny*, one of only three members of the subclass of Martian meteorites known as chassignites. It also contains objects of inestimable value, such as

a lunar rock from the Apollo 17 mission, donated to the Vatican in 1972 by the United States government.

These meteorites are time capsules that preserve information about the history and origins of our Solar System. They have enormous historical, scientific, and even economic value — some of the rarest specimens have a market value of more than €1,000 per gram.

The Vatican Observatory has a laboratory where meteorites and the scientific value of these samples are analyzed. Although we do not have the budget for the multimillion-dollar machines required for chemical and isotopic analyses, we have found a niche in measuring physical properties, particularly density and porosity. The laboratory evolved from the Observatory's astrophysical laboratory, where in the 1930s and 1940s the field of spectroscopic analysis of metals and minerals was developed (the journal *Spectrochimica Acta* was founded at the Vatican Observatory). Today the old spectroscopic instruments have been replaced by desktop tools for measuring the volume and density of meteorites. The collection is also made available to other researchers around the world who require samples for their scientific studies. Typically, we lend about ten samples per year for research at other institutions.

Recently, in an effort to better document this valuable meteorite collection, we have begun working with 3D scanning. We acquired a structured-light scanner (SLS) that uses photogrammetry to create a full-color 3D model of each sample on a computer. Once completed, we will have a three-dimensional record of every specimen that will not only serve as a valuable reference for others but will also help prevent losses and document any damage that might occur during meteorite loans. In addition, the scans facilitate research because we can calculate volumes and densities directly from the computer models.

The meteorite collection is a precious resource entrusted to the Vatican Observatory, which has carefully preserved and slowly expanded it over the past 100 years. Its scientific value has been demonstrated by numerous articles and publications resulting from research conducted on these rare stones. Visitors to our headquarters often arrive with the specific intention of seeing the collection. We continue to find ways to improve the documentation of this treasure, which we hope to make increasingly accessible to researchers and colleagues. Looking to the future, the collection will continue to grow in size and importance.

THE DIALOGUE BETWEEN SCIENCE AND FAITH: LEGACY AND NEW CHALLENGES

Fr. José Gabriel Funes, SJ
Vatican Observatory

We live on an accelerated planet, within an accelerated universe, and often we do not realize it. The universe is expanding at an accelerated rate due to dark energy; the Earth, in its orbit around the Sun, experiences the acceleration of gravitational force. But perhaps the worst thing that can happen to us is to be unaware that we live within a culture subject to accelerated change.

Today we often hear it repeated that "change is all or nothing." It seems to me that this expression reflects an ideology that seeks to transform society and individuals violently, without respecting the rhythms of social and personal processes. In fact, accelerationism is a current of thought that argues that technological and social processes should not be slowed down but intensified in order to precipitate a radical transformation of the system. Certainly we must change, spiritually convert ourselves now, especially during Lent, but we must be careful that ideas do not destroy the most vulnerable people, further deteriorating the social relationships among the different actors that make up the social fabric.

I confess that in recent times I sometimes feel as though I am part of an episode of *Black Mirror* or one of the films in the *Matrix* series. We struggle to distinguish virtual and augmented reality from news portals that claim to be serious and objective, from social networks and memes that tell an epic story of superheroes battling windmills—battles that consume enormous human and economic resources while, along the way, many of our brothers and sisters whom the system expels are left abandoned.

Pope Leo addressed the subject of Artificial Intelligence and its challenges in his Message for the World Day of Social Communications. As the Pope notes, the anthropological question is the central challenge. This is the ancient question that humanity has always asked and that remains ever relevant: "What are human beings that you are mindful of them, or a son of man, that you care for them?" (Ps 8:5). A renewed dialogue between science and faith must place the human being at the center and reflect on his relationship with nature and technology.

In my recent years of study, I have arrived at this anthropological question through two intertwined paths. First, the search for intelligent extraterrestrial life requires investigating who Homo sapiens is, since we are, in some way, interested in communicating with a cosmic alter ego. Second, the progress of Artificial Intelligence leads us — unjustifiably, in my opinion — to compare it with human intelligence. The emergence of intelligence in the universe, from biological evolution to artificial systems, represents one of the deepest mysteries confronting contemporary science, philosophy, and religion today. Both paths — the search for cosmic intelligences and the creation of artificial intelligences — bring us back to the same fundamental question: *who are we?*

Up to this point, we might think that the question of what it means to be human is a purely academic discussion. Nevertheless, each of us has an anthropological perspective that shapes our daily decisions, which also define our path as a society.

The Vatican Observatory has played a significant role in promoting the dialogue between science and faith, particularly during the pontificate of Saint John Paul II. The 1988 letter to the Director of the Observatory, Fr. George Coyne, SJ, on the occasion of the third centenary of Newton's *Principia*, remains a fundamental document. The Study Weeks organized by the Observatory on topics such as cosmology, biological evolution, and neuroscience have created spaces of encounter among scientists, philosophers, and theologians. In the words of Pope Leo XIV, the Observatory can "offer a '*diakonia* of culture', fewer lecterns and more tables where people can sit together, without unnecessary hierarchies, to touch the wounds of history and seek, in the Spirit, wisdom born from the life of peoples" (*Drawing New Maps of Hope*, 9.3).

For decades we have witnessed a divorce between science and the humanities. Today the dialogue faces unprecedented questions. Artificial Intelligence raises questions about the meaning of intelligence, consciousness, and human dignity. Astrobiology, with its search for extraterrestrial life, raises theological questions about the uniqueness of creation and the Incarnation. Climate change demands an ethical reflection on humanity's responsibility toward creation. These challenges highlight the continuing relevance of the anthropological question and the worldview it entails. More than ever, dialogue requires interdisciplinarity. We need a shared effort in which scientists, philosophers, and theologians listen to one another and allow themselves to be questioned by one another. The Vatican Observatory has the credibility to convene experts on the topics mentioned above.

For this very reason, the Vatican Observatory — faithful to its tradition of organizing interdisciplinary study weeks that bring together leading scholars to address fundamental questions about the nature of reality and humanity's place within it — proposes a Study Week for May 2028 entitled "An Intelligent Universe," dedicated to exploring intelligence in its many manifestations — from biological to artificial — within a space that integrates scientific, philosophical, and religious perspectives. The objectives are ambitious but necessary: to bring together scientists, philosophers, and theologians to examine intelligence as a cosmic phenomenon; to promote an authentic interdisciplinary dialogue that develops conceptual frameworks for understanding different forms of intelligence and their meaning for human self-understanding; to address the ethical implications of the development of Artificial Intelligence and space exploration; to produce academic publications that advance the dialogue among science, philosophy, and religion on these fundamental issues.

In accelerated times, the Christian is challenged not to give in either to fear or to haste. The psalmist's question still resounds, not as a relic of the past but as a compass for the future. Our challenge is to inhabit this time with clarity and hope, knowing that the truth about the human being is rooted in that horizon of meaning given to us by the Lord of cosmic and human history.

METEOROLOGY AT THE VATICAN OBSERVATORY

Fr. Bayu Risanto, SJ
Vatican Observatory

Raising awareness about climate change: the historical connection between the Vatican Observatory and weather forecasting

Meteorology is an indispensable science in today's world. From managing everyday personal activities to transporting goods across oceans, planning routes for commercial flights, and even managing insurance companies, people rely on weather forecasts. The history of forecasting dates back to the 1800s, but modern forecasting techniques and methods as we know them today began during the Second World War. Since then, weather prediction has been based on the equations of fluid dynamics. Unfortunately, the atmosphere is chaotic in nature and solving these equations would require days, if not weeks. With the advent of modern computers in the 1950s, meteorological models became the first set of mathematical equations to take advantage of fast computational capabilities, such as those of the Electronic Discrete Variable Automatic Calculator (EDVAC) at the University of Pennsylvania.

Around the 1960s, the capabilities of these models expanded from daily weather forecasting to climate projections. Today, reports by the Intergovernmental Panel on Climate Change (IPCC) discuss results from climate models developed under different possible scenarios, ranging from those predicting the impact of zero carbon emissions in the coming decades to those projecting the consequences of increasing carbon emissions each decade. These models are extremely useful not only for informing policymakers about environmental decisions but also for raising public awareness that anthropogenic (human-caused) climate change is a serious issue. For this demanding work, the IPCC received the Nobel Peace Prize in 2007. Syukuro Manabe of Princeton University and Klaus Hasselmann of the Max Planck Institute for Meteorology were awarded the Nobel Prize in Physics in 2021 for pioneering the physical modeling of Earth's climate, quantifying its variability, and reliably predicting global warming.

Where does the Church stand in all this? During the 35th General Congregation in 2008, the Jesuits raised concerns about climate change and environmental degradation. They called on all their institutions and works to promote awareness and undertake necessary actions to address these environmental challenges. More recently, in 2015, Pope Francis published the encyclical *Laudato Sì'*, addressing both environmental and social issues of our time. He reminds every human being that injustice committed against our common home is equal to injustice committed against our poor and marginalized brothers and sisters. He invites not only Catholics, but all people of good will, to a *reformatio vitae* (a reform of life). Since then, the spirit of *Laudato Sì'* has spread among people and institutions worldwide.

The Vatican Observatory, which has observed and studied the sky since 1871, also turns its gaze toward Earth, its home. One concrete action undertaken in recent years has been harnessing energy from our star, the Sun, by installing a series of solar panels on the roof of the Vatican Observatory headquarters in Tucson, Arizona. The energy that powers electronic devices—from lamps to refrigerators to computers—now comes 100% directly from our star, visible almost year-round in the clear skies of the Arizona desert. This significantly reduces energy consumption. Another sign of the Observatory's environmental commitment was my appointment as a meteorologist (atmospheric scientist) to work on weather modeling research and gradually on climate studies.

However, I am not the only meteorologist in the history of the Vatican Observatory. Several Jesuits and lay scientists have worked in the field of meteorology. Angelo Secchi, S.J., known as the father of astrophysics, was among them. He was in fact a passionate meteorologist of his time. He built the first instrument called a meteograph, which recorded daily meteorological data, including temperature, wind direction and speed, and atmospheric pressure. For the meteograph, Secchi received the Grand Prize gold medal at the Paris Universal Exposition in 1867. His passion for meteorology aimed at understanding atmospheric dynamics and, through that understanding, developing forecasts that could help inform people about future weather conditions.

Today, meteorology and climatology rely extensively on supercomputers to analyze petabytes of data streaming every second from satellites and ground-based observations in order to forecast future weather and climate. The Vatican Observatory does not need its own observation sites. As a researcher, my work relies heavily on the access to datasets, computational resources, creativity, and collaboration with atmospheric scientists worldwide to contribute to understanding the atmosphere and improving weather forecasts and climate projections. This represents the true contribution that the Vatican Observatory can today offer humanity on behalf of the Church.

To achieve this mission, the Observatory continues collaborating with colleagues in the United States, Mexico, Saudi Arabia, and countries across South America. Now working on behalf of the Vatican Observatory, research activities range from data assimilation and cloud monitoring to extreme weather forecasting and climate projections for the entire South American continent. For the first time, my research on data assimilation on behalf of the Vatican Observatory was presented at the European Geosciences Union General Assembly in Vienna in 2025, where it was well received. Although too technical and complex to explain here, the results offer hope for improving rainfall forecasts in regions where observational data are limited or absent. Regarding climate projections, my position calls for the participation in a working group currently developing model scenarios involving changes in South American tropical forest landscapes. Researchers are eager to understand how these changes will influence South American weather patterns.

With recent developments in Artificial Intelligence and Machine Learning (AI/ML), the atmospheric modeling community is exploring ways to apply these technologies to weather forecasting. Thanks to the availability of observational data collected over many decades and reanalysis models, computers can now be trained to recognize atmospheric patterns and behaviors, with the hope that they may contribute to forecasting in the future. One of the current challenges is determining whether AI/ML-based systems can produce short-term weather forecasts — such as 24-hour predictions — with performance comparable to or better than traditional physics-based models coupled with data assimilation techniques.

Some researchers in the modeling community believe that AI/ML cannot yet be relied upon entirely for weather forecasting and that physical models remain essential. One promising approach is to use AI/ML to handle certain nonlinear calculations within atmospheric models. This would allow models to run faster and potentially reduce uncertainties in some variables.

Although we live within Earth's atmosphere and breathe air every second, much remains unknown. There will therefore be many opportunities for future work in meteorology and atmospheric sciences, and the Vatican Observatory can continue to make meaningful contributions.

VATICAN OBSERVATORY: A MONTH WITH THE YOUNG ASTRONOMERS OF THE FUTURE

Fr. David Brown, SJ
Vatican Observatory

The biennial Summer School cultivates international talent by focusing on inclusion, scientific excellence, and global collaboration at the new frontiers of Astronomy

One of the most important events of the Vatican Observatory is the month-long Summer School for advanced astronomy students, held every two years at the Observatory's headquarters in Castel Gandolfo outside Rome. Initially proposed by the late Fr. Martin McCarthy, SJ, the Vatican Observatory Summer School (VOSS) welcomes students who are completing their bachelor's degree or beginning graduate studies and who intend to pursue a career in astronomy. Founded in 1986, the school hosts 25 students from around the world, with a strong commitment to supporting students from developing countries. Faculty members come from some of the best universities worldwide. One of the distinctive features of the school is the bonds formed among the students during these four weeks, relationships that often last a lifetime. These summer courses have enabled former Vatican Observatory Summer School students to attain prominent academic positions at universities around the world. In recent years, an increasing number of the school's instructors have themselves been former students of earlier sessions. It is inspiring to witness their generosity in giving back to new generations what they themselves once received freely.

The theme of this year's Summer School, held at the Vatican Observatory from June 1 to June 27, 2025, was "*Exploring the Universe with the JWST: The First Three Years.*" The James Webb Space Telescope (JWST) is the new space telescope and successor to the Hubble Space Telescope; the images and data it produces are deepening humanity's understanding of the cosmos. This year, the School was led by Fr. David Brown, SJ, who served as Dean of the Summer School, acting as a link between faculty, students, staff, the Jesuit community, and the Director of the Observatory. Drs. Eiichi Egami, Almudena Alonso Herrero, Roberto Maiolino, Maria Drozdovskaya, and Thomas Greene served on the School's faculty, all experts in various aspects of the Webb telescope. Three of the instructors were themselves former Summer School students. The faculty guided the students through lectures and specific research projects. The 25 students were selected from an international pool of applicants, with more than 50% of them women. The selected students demonstrated not only strong academic preparation but also a strong sense of community and great enthusiasm.

The Summer Schools are very intensive, featuring four weeks of daily lectures, exercises, and guest speakers. In addition, the Vatican Observatory provides meals for students and faculty and organizes several social evening events on weekends. This year, cultural excursions were organized for the students to places such as Subiaco, Florence, and Ostia Antica. To contribute to the international atmosphere of the School, the Observatory invited the Ambassadors to the Holy See from the students' respective home countries to visit the Observatory and have lunch with their students. Several media organizations, sometimes from the same countries as some of the students, visited the Observatory to produce reports on the work of the VOSS. Sr. Raffaella Petrini and Giuseppe Puglisi-Alibrandi, the Governorate's President and Secretary General respectively, visited and spoke with the students of the School. Finally, on June 16, 2025, the VOSS2025 faculty and students, along with the entire staff of the Observatory, had the privilege of being received in a private audience by Pope Leo XIV.

The School was made possible through the generous support of the Vatican Observatory Foundation, based in the United States of America. Thanks to the generosity of our benefactors, the Vatican Observatory can welcome students from all over the world regardless of their financial circumstances. This financial support helps the Vatican Observatory fulfill a vital and essential role: supporting young astronomers from less privileged backgrounds, especially in countries where astronomy is not yet highly developed.

In addition to the Summer School, the Foundation supports the McCarthy–Stoeger Fellowship, which is awarded to a former Summer School student. The **McCarthy–Stoeger Fellowship** covers the first two years of a PhD in astronomy at the University of Arizona. It is named after the late Frs. Martin McCarthy, SJ, and William Stoeger, SJ, two prominent members of the Vatican Observatory staff. The Vatican Observatory McCarthy–Stoeger Fellowship for the period 2026–2028 has been awarded to the Chilean student Hugo Cortés Muñoz, who attended the 2025 Summer School. He is currently enrolled in a master's degree program in astronomy at the University of Chile, where he is working on a thesis in extragalactic observational astronomy focused on studying the environments surrounding galaxies using very luminous objects such as quasars. He hopes to graduate in the coming months and begin a doctoral program by 2026.

Cortés Muñoz was born in 2000 in Santiago, Chile, where he grew up. His high school physics teacher convinced him that the new telescopes being built in northern Chile offered great opportunities for Chileans to become part of the international scientific community. Cortés Muñoz initially enrolled in engineering at the University of Chile before switching to astronomy. Interestingly, one of those new telescopes in Chile now bears the name of one of the instructors of the very first Summer School in 1986: Vera Rubin.

With many alumni now spread across astronomy faculties around the world, the Vatican Observatory Summer School and the McCarthy–Stoeger Fellowship bring great recognition to the Observatory and to the Vatican as a whole. Former students enjoy returning to visit the Observatory in Castel Gandolfo, a sign of the deep respect and affection the Observatory enjoys within the international astronomy community.

ADDRESS OF THE HOLY FATHER TO THE PARTICIPANTS OF THE SUMMER SCHOOL OF ASTROPHYSICS PROMOTED BY THE VATICAN OBSERVATORY

Consistory Hall, Monday, 16 June 2025

I am pleased to have this opportunity to greet all of you, students and scholars from various parts of the world who are taking part in the Vatican Observatory Summer School. I offer you my prayerful good wishes that this experience of living and studying together will not only be academically and personally enriching, but also help to develop friendships and forms of collaboration that can only contribute to the progress of science in the service of our one human family.

This year's Summer School – I am told – is devoted to the theme, Exploring the Universe with the James Webb Space Telescope. *Surely, this must be an exciting time to be an astronomer! Thanks to that truly remarkable instrument, for the first time we are able to peer deeply into the atmosphere of exoplanets where life may be developing and study the nebulae where planetary systems themselves are forming. With Webb, we can even trace the ancient light of distant galaxies, which speaks of the very beginning of our universe.*

*The authors of sacred Scripture, writing so many centuries ago, did not have the benefit of this privilege. Yet their poetic and religious imagination pondered what the moment of creation must have been like, when "the stars shone in their watches and rejoiced; and their Creator called them and they said, 'Here we are!', shining with gladness for him who made them" (*Baruch *3:34). In our own day, do not the James Webb images also fill us with wonder, and indeed a mysterious joy, as we contemplate their sublime beauty?*

The Space Telescope science team has worked hard to make these images available to the general public, for which all of us can be grateful. In a special way, though, all of you who are taking part in the Summer School have been given the knowledge and training that can enable you to use this amazing instrument in order to expand our knowledge of the cosmos of which we are a tiny but meaningful part.

Of course, none of you have come to this point all by yourself. Each of you is part of a much greater community. Think of all the people over the last thirty years who worked to build the Space Telescope and its instruments, and those who worked to develop the scientific ideas that it was designed to test. Along with the contribution of your fellow scientists, engineers and mathematicians, it was also with the support of your families and so many of your friends that you have been able to appreciate and take part in this wonderful enterprise, which has enabled us to see the world around us in a new way.

Never forget, then, that what you are doing is meant to benefit all of us. Be generous in sharing what you learn and what you experience, as best you can and however you can. Do not hesitate to share the joy and the amazement born of your contemplation of the "seeds" that, in the words of Saint Augustine, God has sown in the harmony of the universe (cf. De Genesis ad Litteram, *V, 23, 44-45). The more joy you share, the more joy you create, and in this way, through your pursuit of knowledge, each of you can contribute to building a more peaceful and just world.*

With these thoughts, my friends, I renew my thanks for your visit and I assure you of my prayers for you, your families and your work and upon all of you, I willingly invoke God's blessings of wisdom and understanding, of joy and peace.

God bless you!

WELCOME TO THE VATICAN OBSERVATORY

Fr. Jacek Olczyk, SJ
Assistant to the Director of the Vatican Observatory

For nearly a century, the Vatican Observatory has played an important role in the dissemination of astronomical knowledge, inspiring visitors and fostering dialogue among students, researchers, and pilgrims from around the world. In collaboration with the Vatican Museums, it organizes guided tours and astronomical observing sessions at the Observatory, bringing the public closer both to the universe and to the rich cultural heritage of the Vatican.

Traveling south along the Via Appia, the profile of the Apostolic Palace of Castel Gandolfo can already be clearly seen from afar. On its rooftops stand out two domes, immediately recognizable yet very different from those that crown churches: they shelter not altars or relics, but instruments of observation that open windows onto the most remote and unknown corners of the sky. These are the astronomical domes of the Vatican Observatory, which for nearly a century have enabled humanity to glimpse the universe and guided observers toward the depths of space. One can still see the motto engraved by Pope Pius XI near the photographic dome: "*Deum Creatorem, venite adoremus!*"—inspired by the words of the Magi: "*We have seen his star and have come to adore him!*" An invitation that has accompanied generations of astronomers in their nightly work and continues to speak to visitors.

Today the four telescopes are open to the public. The Domes of the Apostolic Palace house a visual telescope and a double astrograph, instruments that allow the sky to be observed and photographed with great precision. Here visitors can watch a short film about the history of the Observatory and admire a selection of astronomical instruments illustrating the evolution of scientific research. The Barberini Domes, on the other hand, house the Schmidt telescope, the *Carte du Ciel* astrograph, and a large museum space. Today the four telescopes are open to visitors and are of purely historical interest since, due to the increasing light pollution that has become evident since the 1970s, the telescope used by the Vatican Observatory for astronomical observation and research is the VATT (Vatican Advanced Technology Telescope), built in the 1980s in Tucson, Arizona.

The Vatican Observatory is not only a scientific observatory but also a place of education and a bridge between history, science, and culture. Fourteen Jesuits currently work at the

Observatory. Despite their small number and their commitment to research, they welcomed visitors of every age and background over the past year. Among them were local high school students, university professors, international researchers, diplomats to the Holy See, and numerous religious groups — Jesuits, Dominicans, Salesians, Carmelites, and others — offering opportunities for dialogue among faith, science, and contemplation of creation.

In recent years the Observatory has undertaken a path of increasingly broad openness to the public, thanks to its collaboration with the Directorate of the Vatican Museums. On August 3, 2023, the official program of guided tours to the Observatory and the Antiquarium was launched, departing from the Pontifical Palace. Since 2024 it has also been possible to visit without an official guide, provided that visitors are accompanied by accredited staff or by an astronomer from the Observatory, making the experience more flexible and personalized.

Also since 2024, public visits to the *Carte du Ciel* and Schmidt telescopes in the Barberini Domes have been organized: groups of up to 25 people, on five days each month, around the First Quarter of the Moon. Evening observing sessions under the stars, guided by authorized astronomers, have also been introduced and have been met with growing success.

October 19, 2024 marked another significant milestone: the opening to the public of the Astronomical Domes of the Papal Palace. In the first months of 2025 more than 7,000 visitors were recorded, adding to the 1,880 visitors of 2024. Visits dedicated exclusively to the Observatory have also shown steady growth: from 225 visitors in 2023 to 447 in 2024, and already 332 in the first months of 2025.

As part of the Jubilee year, the Vatican Observatory, in collaboration with Johns Hopkins University and the Space Telescope Science Institute (STScI), organized the exhibition "*Enchanted by Wonder*" at the Barberini Domes of the Pontifical Villas. The exhibition celebrates the sense of awe inspired by images of the cosmos captured by the Hubble and James Webb space telescopes. Echoing the words of Pope Leo XIV, the exhibition brings together beauty and scientific knowledge, presenting planets, newborn stars, distant galaxies, and spectacular phenomena that reveal the evolution of the universe. The exhibition path, enriched by contributions from scientists of Johns Hopkins University and the Space Telescope Science Institute, guides visitors on a journey through the discoveries made possible by these extraordinary instruments. The exhibition represents an additional attraction for visitors to Castel Gandolfo.

This path of openness and welcome is the result of a collective effort. The synergy with the Directorate of the Vatican Museums has proved essential in making the visitor routes operational and accessible, while at the same time ensuring safety, quality, and scientific rigor.

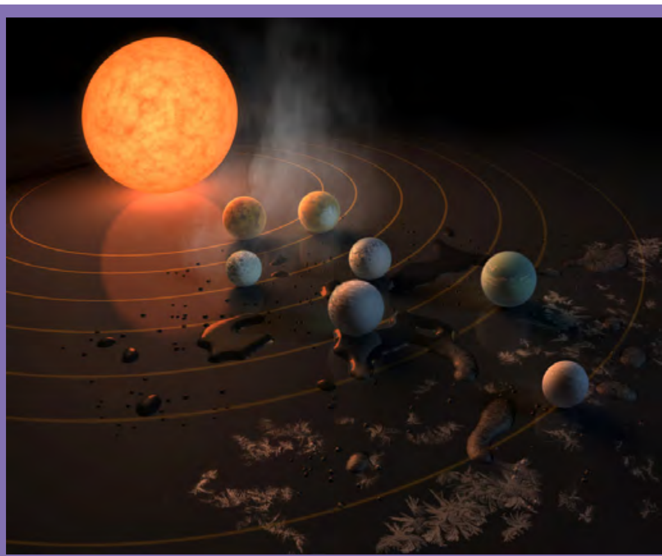
Today the Vatican Observatory continues to be not only a scientific observatory of international importance, but also a place where knowledge intertwines with education, wonder, and encounters among people and cultures. Beneath its domes, the sky continues to offer students, researchers, religious visitors, and pilgrims a unique experience in which science, faith, and beauty meet in a harmonious and profound way.

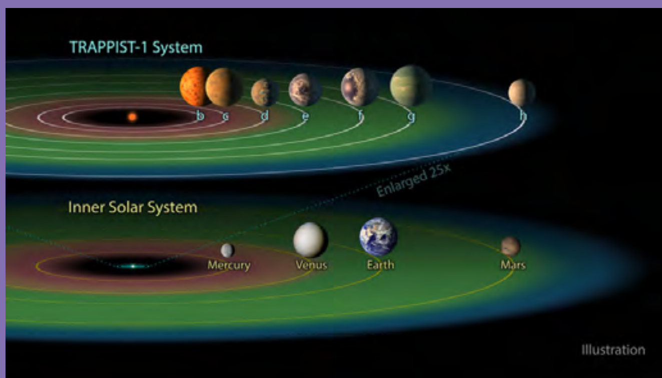
EXOPLANETS: ARE WE ALONE IN THE UNIVERSE?

Fr. Richard D'Souza, SJ
Director, Vatican Observatory

Human beings have always been haunted by three fundamental questions: **Where do we come from? Where are we going? And are we alone in the Universe?** As modern astronomy matured, that last question evolved from ancient wonder into one of science's most urgent pursuits. For most of human history, the planets of our solar system were the only worlds we knew, yet the more carefully we studied them, the clearer it became that none were presently hospitable to life. The Search for Extra-Terrestrial Intelligence (SETI) has for decades scanned the skies for anomalous radio signals that might betray the existence of a technological civilization elsewhere, thus far without success. Meanwhile, the question of whether other stars harbored their own planets remained purely philosophical — a matter of speculation rather than science. That changed dramatically in 1992, when astronomers detected the first confirmed exoplanets orbiting a pulsar, and again in 1995, when Michel Mayor and Didier Queloz discovered the first planet orbiting a sun-like star, 51 Pegasi b — a landmark achievement for which they were awarded the Nobel Prize in Physics in 2019. Notably, Queloz also served as a faculty member at one of the Vatican Observatory Summer Schools, a fitting connection given the profound questions their discovery reopened. Since then, the floodgates have burst open. We now know that planets are not rare cosmic accidents but are instead an almost universal feature of stars, and scientists estimate that within our Galaxy alone, there are billions upon billions of worlds waiting to be understood.

Astronomers use several clever techniques to detect exoplanets, since these distant worlds are far too small and faint to be seen directly through a telescope. The most successful method is the **transit method**, where scientists monitor a star's brightness over time and look for tiny, periodic dips that occur when a planet passes in front of it — this is how NASA's Kepler and TESS missions have found thousands of worlds. Another powerful approach is the **radial velocity method**, which detects the subtle gravitational "wobble" a planet induces in its host star; as the planet orbits, it tugs the star slightly toward and away from Earth, causing measurable shifts in the star's light spectrum. The **gravitational microlensing** technique watches for a distant star's





light to briefly brighten when a planet-hosting star passes in front of it, bending and magnifying the light like a lens. Finally, **direct imaging** — though extremely challenging — uses powerful telescopes equipped with coronagraphs to block a star's glare and photograph orbiting planets directly, which works best for large, young planets far from their stars. We now know of more than 6000 confirmed exoplanets, with thousands more candidates awaiting verification, revealing an astonishing diversity among them.

The sheer variety of exoplanets has upended our assumptions about what planetary systems look like. Before the first discoveries, astronomers expected other systems to resemble our own — small rocky worlds close to their star, gas giants further out, everything orderly and well-spaced. Reality proved far stranger. We found "hot Jupiters," gas giants orbiting so close to their stars that a year lasts only a few days and surface temperatures reach thousands of degrees. We found "super-Earths," rocky worlds larger than our own but smaller than Neptune, a class of planet that doesn't even exist in our solar system. We found planets orbiting binary stars — real-life Tatooines with twin suns setting on their horizons.

The discovery that captivates the public imagination most is the possibility of an Earth-like planet in the habitable zone of its star. The habitable zone of a star is the range of orbital distances at which a planet could theoretically maintain liquid water on its surface — not so hot that water boils away, and not so cold that it freezes solid. This zone is not a fixed distance but varies depending on the size, temperature, and luminosity of the host star. Around a small, cool red dwarf star, the habitable zone sits very close in, sometimes just a fraction of the distance between Earth and the Sun, while around a larger, hotter star like an F-type, it extends much farther out. Our own Sun's habitable zone stretches roughly from about 0.95 to 1.67 the distance of the Earth and the Sun, placing Earth comfortably within it and Mars tantalizingly near its outer edge. Several compelling candidates of Earth-like exoplanets within the habitable zone have been identified. The TRAPPIST-1 system, a mere 40 light-years away, contains seven roughly Earth-sized planets, three of which sit within the habitable zone.

However, scientists are careful to note that being in the habitable zone is a necessary but not sufficient condition for life — a planet also needs the right atmospheric composition, geological activity, magnetic field, and other factors to truly be hospitable. Proxima Centauri b, orbiting our nearest stellar neighbor, is within the star's habitable zone, though its host star's violent flares may make conditions hostile to life.

Finding a planet the right size, in the right orbit, around the right kind of star is only the beginning. The next challenge is understanding what these worlds are actually like — whether they have atmospheres, what those atmospheres are made of, and whether the conditions for life as we know it could exist there. The challenge is enormous — exoplanet atmospheres are incredibly faint signals buried in the overwhelming light of their host stars — but next-generation observatories and space missions are steadily pushing the boundaries of what is detectable, keeping the tantalizing possibility of finding life beyond Earth firmly within the realm of science.

In recent years, astronomers have developed several promising strategies to search for biosignatures in an exoplanet's atmosphere. The primary approach involves analyzing the atmospheric composition of exoplanets through a technique called **transmission spectroscopy**, where scientists study how a star's light filters through a planet's atmosphere during a transit — different molecules absorb light at distinct wavelengths, leaving behind a chemical fingerprint that powerful telescopes like the James Webb Space Telescope (JWST) can decode. Scientists search specifically for **biosignatures**, which are chemical signs that are strongly associated with biological processes, such as oxygen, ozone, methane, and nitrous oxide; the simultaneous presence of oxygen and methane is particularly exciting, since these gases react with each other and would quickly disappear without a constant biological source to replenish them. Beyond atmospheric chemistry, researchers also look for **surface biosignatures**, such as the "red edge" — a sharp spike in infrared reflectance that is characteristic of photosynthetic vegetation on Earth and might be detectable on other worlds.

Till date, no confirmed biosignatures in exoplanets have been found. But the developments in techonology and the new generation of space telescopes planned – make it very probable that within a few years, scientists may discover indirect signs of life on other planets. It is important to reiterate that we are not talking about intellegent life, but of the existence of basic forms of life – including viruses, bacteria, fungi and other basic lifeforms. Yet, the consequences of such a discovery will be enormous.

The discovery of such basic forms of life on another planet would arguably be one of the most profound theological and philosophical events in human history, forcing every major religious tradition to wrestle with questions that their ancient texts and doctrines never explicitly anticipated. For many Christians, particularly those in more literalist traditions, the challenge would be significant — if humanity was created in God's image and Earth is the divinely appointed stage for salvation history, where does extraterrestrial life fit within that narrative? However, many Catholic theologians have already begun engaging with this possibility, arguing that a vast, life-filled cosmos would actually magnify rather than diminish the glory of a creator God, reflecting a divine creativity and generosity that stretches far beyond our small corner of the universe. The Pontifical Academy of Science along with the Vatican Observatory organized one of its first workshops on Astrobiology already in 2009 – wrestling with these themes. In an interview with the L'Osservatorio Romano later in the same year, "*I think there isn't [a contradiction]. Just as there is a multiplicity of creatures over the earth, so there could be other beings, even intelligent [beings], created by God ….This is not in contradiction with our faith, because we cannot establish limits to God's creative freedom. To say it with St Francis, if we can consider some earthly creatures as 'brothers' or 'sisters', why could we not speak of a 'brother alien'? He would also belong to the creation.*" Ultimately, the discovery of life beyond Earth would not necessarily destroy religion, but it would almost certainly catalyze one of the greatest periods of theological reexamination and reinterpretation since Copernicus displaced Earth from the center of the cosmos, challenging believers everywhere to expand their conception of the sacred to encompass a far grander and more wondrous universe than their traditions had previously imagined.

However, exoplanet science is already causing a revolution closer to home: it has reframed our understanding of Earth itself. Our planet is not the inevitable result of some cosmic template — it is one outcome among an almost unimaginable range of possibilities. Some planetary systems are ancient, their worlds having had billions of extra years to evolve compared to our own. Others orbit in configurations so chaotic that stable orbits, let alone life, seem impossible. We are only a few decades into the exoplanet era, and already the universe looks far more crowded — and far more interesting — than it did before. The question is no longer whether other planets exist. The question, increasingly within reach of answering, is whether any of them are home to life, and whether this life is looking back at us.