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ANNUAL REPORT 2019

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Forty Years of Photometry

SPECOLA VATICANA

VATICAN OBSERVATORY

ANNUAL REPORT 2019

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Other Scholars:

- CLAUDIO COSTA - *Technical Expert*
- MATTEO GALAVERNI - *Associate Scholar*

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CONTENTS

Chapter ONE

From the Director

How does the work of the Vatican Observatory tie in with the four apostolic priorities of the Society of Jesus proposed this year by Father General Arturo Sosa? We were able to reflect on the nature of our mission when all of the members of the Observatory got together this past summer... a gathering that culminated in a private audience with Pope Francis.

Pope Francis met with the entire scientific staff of the Vatican Observatory on August 30. It was a private gathering; no formal statements, no urgent concerns or profound proclamations. We were just a group of Jesuits and friends… sharing our stories, our hopes, our concerns, our joys; at times, even, our jokes. In the busy year that we describe in this Annual Report, this was the highlight.

All of the Tucson Jesuits of the Specola (except Br. Tom Williams, whose health precludes transatlantic travel) came to our Castel Gandolfo headquarters for two days of meetings before the day of our papal audience. We reviewed the state of the Specola and explored together the ways in which we can engage the public in our core mission of showing the world how the Church supports science. It was a chance to put what we've been doing into a larger context, and a chance to meet and enjoy each other's presence as a community.

The last time we'd gotten together in this manner was in 2012, when José Funes, the director at the time, had gathered the staff on a retreat at Loreto. The first order of business this year was to reflect on what we'd talked about in 2012 and see how much we'd actually accomplished. In fact, many of the dreams that Fr. Funes had raised then have indeed come to pass.

We are now working together more in groups within the Specola. Even though our own individual research projects vary widely, we're finding that there is benefit, both scientific and personal, in finding common topics where our interests intersect.

The way we use the VATT has evolved. The freedom we have running our own telescope has allowed us to participate not just in targets of opportunity but also projects of opportunity, such as the EDEN and PEPSI programs mentioned further in these pages. We've also begun coordinating our efforts in our Science and Faith outreach, writing books and doing programs jointly.

It was especially interesting to see how, back in Loreto, it had been proposed that the abandoned telescope domes in the Papal Gardens near the Barberini Palace could be converted into a museum and visitor's center, including bringing the Carte du Ciel telescope back into use. That is now a reality.

The Holy Father, Pope Francis, and Br. Guy Consolmagno S.J, Director of the Vatican Observatory, sharing a moment of light relief during a private audience this year.

In reviewing our records of the Loreto meeting I was struck by a comment from our religious superior, Paul Mueller. In 2012, he'd pointed out, we'd gone through four major changes in five years: in leadership, location, staff, and the physical set-up of the houses. He recognized that it would take time to get used to all these changes. Since then the pace of change has slowed, but it has not stopped. Still, seven years later, I think we've finally gotten to feel a little more settled in our home.

There's still more we want to do. The importance of adjunct scholars continues to grow; they provide a breadth of research opportunities, and personal voices, that are greatly needed and appreciated within our small observatory. The upgrades to the VATT will make it more flexible and easier to use for projects such as surveys, time-domain astronomy, and pipeline-processed data that are the future of observational astronomy. In Castel Gandolfo, one important remaining goal is to complete a digital catalog of our library and archives, which have become increasingly important resources to historians of science. We have now begun a small but important program of expanding the Vatican meteorite collection, a field where the Specola has become a major player. Though we have a strong Internet presence there is always room to improve this important way of reaching the world, including making our content more international, and building an audio and video studio to make that content more professional.

And we are now using our facilities in Castel Gandolfo to hold several small workshops every year. In the following pages you'll find reports of the IAU Executive Committee meeting that we hosted this past May, the SuperVOSS reunion of our summer schools students in August, and the September workshop on the use of PEPSI (the Potsdam Echelle Polarimetric and Spectroscopic Instrument). Next year, along with our Summer School on the Centres of Galaxies, we are also planning a workshop on the history of spectroscopy.

Every member of the Specola had a chance to tell Pope Francis about his projects. But there was an extra dimension we went into at that audience, an ingredient of our work that makes us a little different from the typical astronomical observatory. We are a group of Catholic priests and brothers, most of us Jesuits like His Holiness. And this past year, the Jesuit Father General, Fr. Arturo Sosa, has proposed four important "apostolic priorities" for the Society of Jesus. These goals are to be central to all that we do. At first blush, one might think that they are all far afield from the work of an astronomical observatory. But, as we were able to tell to the Pope, they are central to who we are both as an institution and as individuals. What are these priorities?

To show the way to God through the Spiritual Exercises and discernment. Providing individual spiritual direction to Religious and lay people is a regular aspect of life outside the lab for many of us, both in Castel Gandolfo and in Tucson. And a number of us have developed retreat programs that we've given around the world, using images and our modern understanding of astronomy to provoke new ways of seeing God in the universe: finding God in all things.

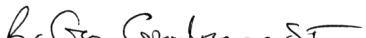
To walk with the poor, the outcasts of the world, those whose dignity has been violated, in a mission of reconciliation and justice. The hunger to satisfy our curiosity, to know and understand – which is a hunger for finding God – is as real and vital to every human as the hunger for food… and all too often something that, like food and shelter, is also denied to the poor and outcast. To deny someone the joy of contemplating the universe is to deny them a part of their humanity. When we reach out, in talks and articles, about the wonder of the work we are so privileged to do, we touch people in nations and continents as widespread and varied as our staff itself… sharing the skies with school children in central Europe, in India, in the Congo, in rural America; writing to death-row prisoners in California, where our astronomical calendars every year provide a little window to a bigger universe; saying Mass for the Little Sisters of the Poor at their home for the aged, and for the inmates of the Velletri prison outside Rome; giving support to our fellow Jesuits working with refugees at the Kino Border Initiative in Nogales, Arizona. We are a bridge connecting those who fear they are forgotten, to a universe that is unforgettable.

To accompany young people in the creation of a hope-filled future. We reach the young in our summer schools and the extensive outreach programs, as described in this report (including my own participation in an online high school class in astronomy with the Jesuit Virtual Learning Academy). We meet them at the universities where we work, and as hosts to groups participating in special programs in Rome. But more than that, astronomy

itself can be a great source of hope, bringing a welcome perspective to a world too often obsessed with the latest headline and the latest scandal. Just consider… this year we celebrated the 1969 Moon landing: by contrast to our ever-fresh memories of those astronauts and what they did, the social crises that so haunted my own youthful consciousness in 1969, the generals in Vietnam, the pop stars at Woodstock, have become ever more forgotten. The universe remains.

To collaborate in the care of our Common Home. The obvious places where the Specola works to care for our planet, supporting dark skies or renewable energy or better practices with our observatory and our travel, are just the beginning our effort. Creation is our home; we study it because we love it. That's true of any scientist, ecologist to zoologist. As astronomers, we just live in a bigger house.

In this year's edition of the Specola Vaticana annual report, I invite you to come inside and see some of the rooms we've opened up in this wonderful home of ours. Let us share with you our stories, our hopes, our concerns, our joys; at times, even, our jokes.



Guy J. Consolmagno, S.J.
Director

Personnel

The feast of Saints Peter and Paul, June 29, was an important date this year for two of the Jesuits at the Specola. Gabriele Gionti made his final vows as a Jesuit at the Gesù Church in Rome, while on the same date Giuseppe Koch celebrated 50 years as a Jesuit priest. Six weeks later, on August 16, Guy Consolmagno celebrated the 30th anniversary of his entrance as a brother into the Society of Jesus.

Fr. Gabriele Gionti S.J., professes his final vows as a Jesuit in Rome's Gesù Church.

As noted in last year's annual report, in the summer of 2018 Adam Hincks returned to Canada to finish his final year of studies leading to ordination and his final degree in theology. On May 11 he was ordained a priest in Toronto, with Corbally, D'Souza, Gionti, and Kikwaya-Eluo representing the Specola at this happy event. Following a year of pastoral work, as is typical for newly ordained priests, he will continue his academic research in cosmology. We look forward to his future collaboration with the Specola.

At the end of 2018, the Specola welcomed Fr. Peter Lah S.J. into our community in Castel Gandolfo. His principle assignment is as a professor of communications at the Gregorian University, but since his arrival he has also volunteered his assistance as a technical advisor in the development of our audiovisual studio in Castel Gandolfo and in various tasks related to press and public relations. We especially appreciate his presence in the community during the winter months, when numbers in Castel Gandolfo dwindle.

Fr. Peter Lah, S.J.

On March 5, Cardinal Giuseppe Bertello, president of the Governatorato of the Vatican City State, presented Fr. Sabino Maffeo with the Vatican honor of the *Croce pro Ecclesia e Pontifice*. As noted in last year's Annual Report, Fr. Maffeo has moved from the Specola to the Jesuit retirement community in Rome, but still remains active (at age 97) working in preparing translations and helping us with materials in our archives.

Following three years of postdoctoral work at the University of Michigan in Ann Arbor, Richard D'Souza

arrived in Castel Gandolfo this summer to continue his research in galactic and extragalactic astronomy. He will also take on responsibility for our historic telescopes and public display areas following on the faithful service in this area from David Brown, who is now shifting the center of his research work to Tucson.

In September, the Specola welcomed Fr. Robert Janusz S.J. as a full time astronomer and member of the Jesuit community. A close collaborator with Boyle, Janusz had been an adjunct member of the Specola since 2005 while teaching at the Ignatianum University and Michael Heller's Center for Interdisciplinary Studies in Kraków. Now in Castel Gandolfo, he will continue his work in information sciences as applied to astronomical data, while also taking on duties of archivist and assisting Koch in updating the library's digital catalog.

In 2019 we welcomed Chris Graney as an adjunct scholar at the Vatican Observatory. Since 2002 he has been a professor of astronomy at Jefferson Community & Technical College in Louisville, Kentucky. He also has the unusual distinction of an expertise in the diverse fields of astronomy, history, and Latin; this has provided him an unusual ability to read and appreciate historic astronomical texts. This has led in recent years to a series of groundbreaking publications on the topic of Galileo's rivals in 17th century astronomy. Along with numerous scholarly publications in the history of astronomy he is the author of two books published by the University of Notre Dame Press: *Setting Aside All Authority: Giovanni Battista Riccioli and the Science against Copernicus in the Age of Galileo* (2015) and *The Mathematical Disquisitions of Locher and Scheiner: The "Booklet of Theses" immortalized by Galileo*, (2017). In addition, since 2016 he has served as the editor of Faith and Science web resource pages of the Vatican Observatory Foundation: www.vofoundation.org/faith-and-science

In memoriam

Former Vatican Observatory Foundation board member (from 2003 - 2009) and good friend of the Specola, Fr. Charles Currie S.J., died January 4. The mother of director emeritus José Funes, Josefina R. de Funes, died on May 12. On December 11, longtime Specola collaborator Dr. Ajoy Dasgupta died in Wales. Dasgupta worked from the 1980s up until 2001 with Boyle and Filippo Smriglio (University of Rome) on computer processing and analysis of CCD photometric imaging observations made at the Kitt Peak 0.9-m telescope and later at the VATT.

We remember them, and all the deceased friends and family of the Specola, in our prayers.

Cardinal Giuseppe Bertello (left in the picture), presents Fr. Sabino Maffeo with the Vatican honor of the Croce pro Ecclesia e Pontifice.

Chapter TWO

Forty Years of Photometry at the Specola

Just as this year the world celebrates the 50th anniversary of the Apollo moon landing, so here at the Specola we mark a significant anniversary: 40 years since the pioneering publication of Father Martin McCarthy and his collaborators on stellar photometry, which laid the groundwork for what has become a major thrust of research at the Vatican Observatory. In that paper, Fr. McCarthy described a program that has been carried out over forty years, three continents, several telescopes, and the careers of several astronomers... and is still ongoing.

What is "photometry"? Starlight links us to the universe, and photometry — literally, the measure of light — lets us read what the universe is telling us in the light of that light.

Photometry detects the information encoded in tiny portions of light quanta, called photons. The intensity of the light we detect is merely a measure of the rate at which photons hit our eyes or detectors; modern electronic detectors can actually count up the photons, one by one. Each photon can be characterized by its color (which is the length of its electromagnetic wave); from the information encoded in these colors, we can determine not only the composition and color of its star of origin, but also how interstellar matter has imprinted itself on the traveling photons.

From the moment it is emitted from a star or other cosmic source, every photon records everything that has happened to it, from its birth, through its interactions with the interstellar matter it travels through on its way to us, to finally all the events that happen to it inside the telescope and detector that we use to record its arrival here on Earth.

To decode the message within each photon, we first had to understand what a photon was. James Clerk Maxwell's (1831-1879) electromagnetic theory in the mid-1860s gave us our first understanding of light as electromagnetic radiation. This was followed in the early 20th century by E. Schrödinger's (1887-1961) development of quantum physics, and Einstein's (1879-1955) theory of the photon. (It was his idea of the photon, not relativity, that earned Einstein his Nobel Prize.) This work not only allowed us to understand how light records information; it also gave us the tools to build better detectors to record and interpret this information.

At the same time that Maxwell's work was being published, Father Angelo Secchi, S.J. (1818-1878) began the modern measurement of stellar spectra. His classification of stars formed the basis of our modern system of spectral classification, and our goal in photometry is the same as his: to measure in detail the amount of light emitted by a star in various colors in order to determine its nature.

Left: Fr. Angelo Secchi S.J., Right: his spectral classification of stars.

Secchi used prisms to split his starlight into its various colors. Photometry, however, uses a different and more sensitive technique: it sorts starlight through specific colored filters and then with highly precise detectors it records the number of photons that pass through each filter.

In fact, the first general measurement of photometry at the Specola began in the 1950s. Since the late 19th century, starlight had been recorded with photographic plates, but in 1955, the Specola got a high-quality new generation photoelectric photometer. In the years 1955-59 astronomers at the Specola used it with three

filters to measure the colors of variable stars. This work helped motivate the construction of a powerful Schmidt photograph telescope in 1957, for studying variable stars and stellar clusters.

A wealth of data was continuing to be recorded on photographic plates, and the new techniques were applied to measure the intensity of the light recorded on a plate by measuring the darkness of the photographic image. To this end, between 1954-1963, a new method of making such photometric measurements from astronomical photographs was invented by Fathers Junkes and Salpeter at the Specola. In 1963-65 a new photometer was constructed at the Specola which could be cooled to -45°C for better sensitivity. Junkes' "micro-photometer" was electronically improved in 1967; again, it was used to measure photographs of stellar spectra.

Later improvements of photometers were made by Salpeter to study the brightness of the Italian sky, in a search for a location for a new Vatican telescope. One result of this work was the first photometric map of the sky over Italy.

The SpectroLab at the Specola in its previous headquarters in the Papal Palace at Castel Gandolfo circa 1960.

However, adapting photometry to the study of stellar classification only began with the 1979 article by Father McCarthy. McCarthy served for several years as commission president of International Astronomical Union (IAU) Commission 25, "Stellar photometry and polarimetry," and Commission 45, "Spectral classification." Through this connection, he was in a privileged position to know the promise and the needs of such a study. This led to McCarthy's landmark 1979 paper.

Schmidt Telescope and Fr. Martin McCarthy.

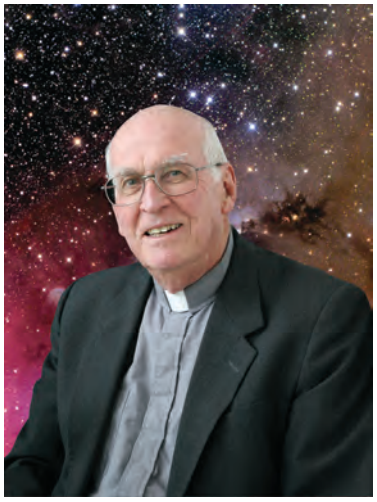
Spectra recorded on photographic plates, as had been done at the Specola since the 1930s, was a well understood technique. By placing a large prism at the aperture of a telescope, each star's light could be spread out into a little streak which recorded its spectra, red at one end of the streak and blue at the other. An entire field of stars could be photographed in this way, with all the stars and all their colors recorded all at once. Preparing and developing the plates required nothing more than a simple darkroom. And for classifying most stars, a trained observer with good eyesight (and a small microscope) could determine each star's type.

But photographic plates suffered from a number of drawbacks. Plates could not easily image both bright and faint stars at the same time. When a star's light is spread out as a spectrum, each color is only weakly illuminated, meaning that the spectra of fainter stars are harder to recognize. And the strict relationship between the brightness of the source and the intensity recorded in the image was only valid for a narrow range of brightnesses (a phenomenon known as "reciprocity failure"). In other words, a star — or a particular color in the spectrum of a given star — that was exactly twice as dark as its neighbor on the photographic negative was not always necessarily exactly twice as bright as its neighbor.

Applying an electronic photometer directly to starlight, rather than just using it to measure the intensity of a photographic plate, solved many of these problems. But

the original photometers were single tubes that could measure only one spot of light at a time. This was useful for measuring the brightness of any particular star, such as the measurements of variable star brightnesses mentioned above. But measuring the entire spectra of a star meant passing the light from a given star through a series of colored filters, each color's intensity recorded in turn.

If each filter allowed a narrow range of color through to the detector, one could eventually map out the entire spectrum of a star. But with narrow filters, less light would arrive at the detector, making fainter signals that would be harder to record… and it would take a longer time to cycle through all the filters to get a useful sense of the star's overall color. If the filters were broader, more light would reach the detector and a stronger signal could be recorded; but if they were too broad, then the differences in color from one star type to another would no longer be recorded. Thus a careful choice of filters was an essential part of photometry. Unfortunately, at that time there was no one standard set of filters that astronomers could agree were the best to do the job.



Fr. George Coyne, S.J.

The beginning of a long term photometric project at the Specola got underway with the urging of its new director, Fr. George Coyne, S.J., who had been appointed in 1978 Coyne, like McCarthy, was also a member of the IAU Commission 25. So was V. Straižys from Vilnius, Lithuania.

Through this commission, Coyne heard Straižys describe a new system of photographic filters devised in Vilnius which seemed to hold great promise for stellar photometry. Later, K. Nandy (Edinburgh Royal Obs.) and F. Smriglio (Università di Roma "La Sapienza") also suggested the Vilius system to Coyne.

When Coyne welcomed a new, young astronomer, Richard Boyle, S.J., to the Specola in 1981, he suggested that Boyle look into this new project. Boyle's Ph.D. was actually in solar astronomy; but this young and energetic solar astronomer soon began to observe stars other than the sun, at night, using the Vilnius photometric system in collaboration with fellow astronomers in Rome, Vilnius, and Edinburgh.

For Boyle, the early 1980s was a time of training in the classical photographic plate methodology. He made his first observations in Castel Gandolfo at the Schmidt telescope, with the close collaboration with Smriglio, who used a similar telescope at the Italian observatory in Campo Imperatore. During the time of his Jesuit Tertianship program in Ireland (1983/1984), Boyle was able to use the Royal Observatory in Edinburgh COSMOS digitizer, then a rare instrument, to transform his analog photographic plates of the stellar cluster M56 into a modern digital format. In 1986 F. Smriglio, R.P. Boyle, V. Straižys, and collaborators published these results; this was Boyle's first paper using the Vilnius Photometric System and hybrid methods of recording and analyzing data.

Meanwhile, Salpeter's survey of the Italian dark skies had also showed the need for a new telescope for astronomical observations, because the sky at Castel Gandolfo had already become too bright to allow scientific observations. The first step was to establish the Vatican Observatory Research Group (VORG) in Tucson, AZ, USA, with collaboration of Steward Observatory (University of Arizona) in the 1980s. In this way Specola astronomers had access to the many telescopes surrounding Tucson.

About this time, a new kind of electronic detector called a Charged Couple Device (or CCD) was becoming known to the members of IAU Commission 25. Each pixel on the chip would do the work of a photometer tube; thus the efficiency of a photographic plate covering a whole field of stars could be recovered, but with the improved accuracy of photometry on each data point. Nandy and Straižys suggested that the Vatican Observatory explore this instrument, and so in 1986 Boyle obtained time to try out CCD observing at the Kitt Peak National Observatory (KPNO) in southern Arizona… using, of course, the Vilnius System. The results of these first two CCD observing runs were published in 1990.

But among astronomers there was still a question of whether the Vilnius system could adequately determine the spectral class of most stars. How did its results compare

with traditional spectra observations, and how could they be compared to observations made by other astronomers using other filter systems? To this end, Boyle began a collaboration with F. Vrba at the USNO in Flagstaff to validate the system. Smriglio, using the Loiano CCD (Università di Bologna), and O. Pintado (CASLEO: Complejo Astronómico El Leoncito) with A.G. Davis Philip, continued to develop CCD methodology for photometry in the system.

To resolve the questions of compatibility, a combination of the Stromgren and Vilnius filter systems was developed. This allowed one to use the well-known Stromgren filters, but with three additional Vilnius system filters. Boyle participated in the standardization of this new "Stromvil" system.

Meanwhile, in 1983-1984, Frs. C. Moss and E. Benedetti S.J. at the VORG in Tucson participated in the development of a photometer at the University of Arizona. And then the new Vatican Advanced Technology Telescope was inaugurated in September of 1993.

Vatican Advanced Technology Telescope (VATT) Mt. Graham, Arizona USA.

The VATT soon became the primary telescope for the Vatican photometry project. Though it saw first light in 1993, at that time it did not yet have its own CCD camera or filters. The first photometric observations that Boyle made at the VATT, using a borrowed CCD and filters, were from January 3, 1996. Eventually the VATT acquired CCD cameras developed at the University of Arizona by Mike Lesser — first a 2K x 2K camera in 1996, followed by a 4K x 4K camera in 2004 – and a full set of Vilnius filters. On Dec 20th 1998, the first series of data images was begun at the VATT. To date, Boyle has made 74 photometry runs at the VATT (plus some others done at Flagstaff). From these, we have 28000 VATT scientific images; about 6000 are calibrating images of M67, while around 22000 images of data exist in our archives.

Such a massive amount of data requires advances in data processing. To that end, Robert Janusz, an expert in information theory, began work with Boyle and the Vilnius group around 2000 from his location at the Ignatianum in Kraków, Poland. He became an adjunct scholar of the Specola in 2005, and now in 2019 he has moved to Rome to work full time at the Specola Vaticana.

Boyle and Janusz continue to collaborate with the Lithuanian photometry group guided by Prof. Straižys, including regular conversations via Skype and yearly face-to-face meetings. As of the end of 2019, the Scopus database lists more than 40 papers where Boyle is a coauthor with the Vilnius Observatory, and more than ten other publications with others in the field. The results of their research have been outlined in every Annual Report since 1996, including this one.

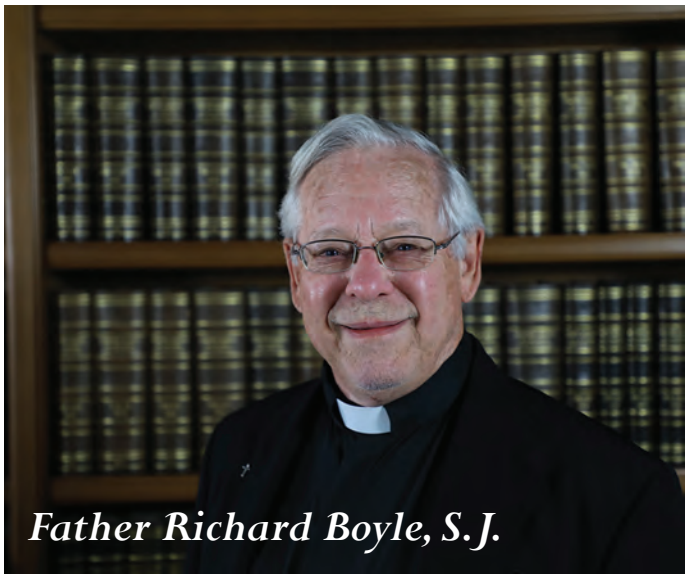
Today, Boyle also applies his photometric techniques to a project on Brown Dwarfs, the EDEN exoplanet project, the studies of lensed Quasars, and astro-seismology. Meanwhile, Boyle also continues to prepare the VATT observation schedule… and the use of the VATT for photometry into the foreseeable future.

Fr. Janusz and Fr. Boyle.

Chapter THREE

2019 A Year in Review

2019 has been the year of the H0liCOW and COSMOGRAIL, of Multimessenger Astrophysics, of mistaken calculations that lead to crucial discoveries. It was a year of reconciling the eternal dialogue of science and faith, of final vows, of deepening dark matter and gathering together at the Vatican Observatory, a place where scientists, staff and scholars "open the book of the Universe".



Father Richard Boyle, S.J.

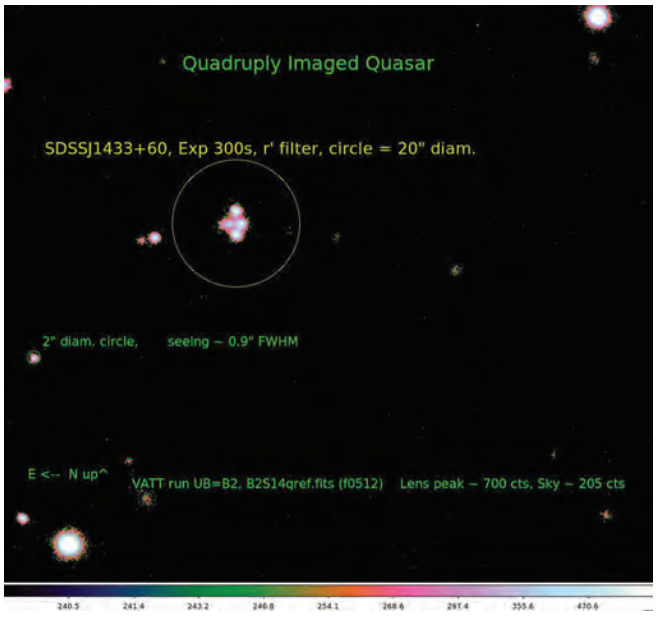
This has been the year of the H0liCOW and COSMOGRAIL projects at the Vatican Advanced Technology Telescope, or VATT in Tucson. Early on GABOR and a colleague from Switzerland's Ecole Polytechnique Fédérale (EPFL) de Lausanne, Prof. Frédéric Courbin, asked me to observe a few gravitationally lensed QSOs, to test the possibility that VATT might play a part in the program. The idea is to regularly monitor a few lensed QSOs for the projects to measure the Hubble constant Ho for the expansion rate of the Universe KM per second per Megaparsec.

Refined measures of Ho with a few percent accuracy reveal cosmologically important information about dark matter, neutrino physics and the spatial curvature of the Universe as well as discovering new physics. Strong gravitational lens systems such as QSOs have time delays in the light-curves of the double or multiple images, arriving at different times from the same single QSO. A QSO at a great distance can have some of its divergent light beams redirected towards us by a strong gravitational field of an intervening galaxy, to give us a second or multiple images of the source QSO.

But any fluctuation of brightness in the source could arrive at our perspective in delayed imagery by different routing. Such a configuration tells a refined tale on the operating expansion of the Universe. The same brightening event at the QSO, but diverted into two slightly different routes, will give that brightening in a delayed time relative to the two images.

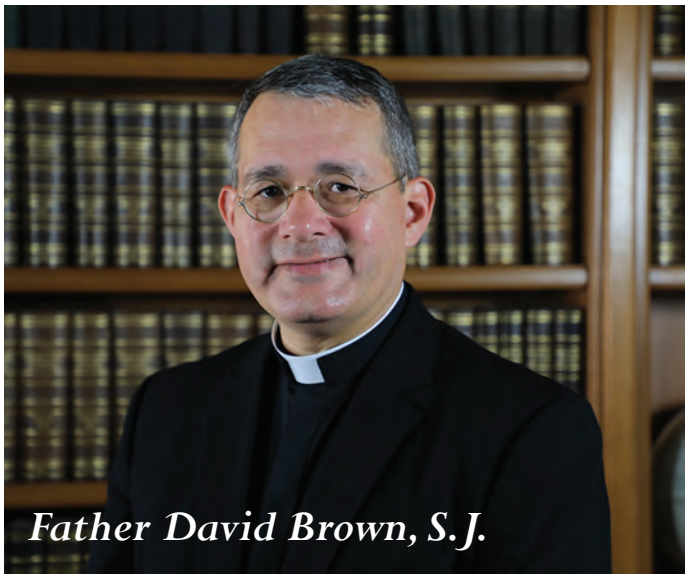
With the constant speed of light, different arrival times of the same brightening event of the source QSO can only mean the pair of images of the QSO came by somewhat different distance routes. And such a configuration gives special leverage on measuring the Hubble constant, Ho to improved accuracy.

For about thirteen years now, the ESO Euler 1.2-m telescope at La Silla, Chile, has monitored a few lensed QSOs on a nightly basis. These types of observations require a spatial resolution that is better than about 1.5 arcseconds and an exposure time in one filter (broadband R or Sloan r') of about 5 min. The test exposures I made in both February and April 2019, demonstrated the VATT's capability with the excellent optics of the VATT mirrors M1 & M2, the seeing of 1" common at the VATT site, and frequent clear skies. However, data monitoring is a painstaking task and the real question remains whether observers using the 4KCCD camera for their own program, can contribute an hour per night to gathering this data for the H0liCOW project.



Quadruply imaged gravitationally lensed quasar SDSSJ1433+60. VATT image, 300 sec., r' filter, seeing ~ 0.9"fwhm

In October, EPFL doctoral students in the H0liCOW program, Martin Millon and Aymeric Galan, joined KIKWAYA and me at VATT for two nights to observe a lensed QSO nicknamed "the parachute" for its likeness. After having seen VATT in action, they now intend to set up software scripts to allow observers to efficiently contain the observing time needed for such regular monitoring of a few prize lensed QSOs.



Father David Brown, S.J.

My 2019 began with an injury, a broken left wrist and a sprained right wrist. It was mid-March before they were properly healed and I could return to my research.

However, the same month brought exciting news of my transfer to the Tucson branch of the Observatory in 2020.

As part of becoming a member of the VATT-PEPSI-TESS group, I travelled to Potsdam, Germany to confer with the German members of the collaboration at the Liebniz Institute of Astrophysics Potsdam during April 7 to 17. The purpose was to meet the members of the group as well as to be briefed on the status of the collaboration and of my role in it. The group has been allotted 50-nights of observing time at the VATT during May-June-July, using the PEPSI (Potsdam Echelle Polarimetric and Spectroscopic Instrument) spectrograph to provide high-resolution spectra for a subset of stars observed by NASA's TESS (Transiting Exoplanet Survey Satellite). My role will be to examine the stellar spectra in order to determine the chemical abundances of the target stars.

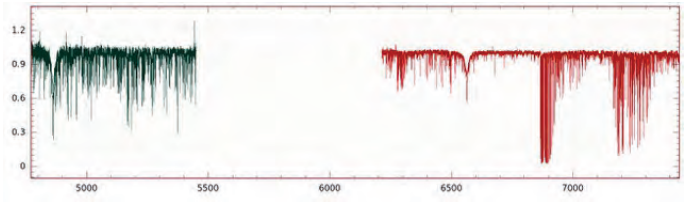
Back in Rome, in May I welcomed a future collaborator, Lorenzo Spina, to the Observatory in order to plan a future collaboration using the VATT telescope. Using high-resolution spectroscopy, the plan is to study Sun-like stars, which might have Earth-like planets orbiting around them, by using a chemical analysis to see if there have been planetary engulfment events in their histories.

On May 31, I left for the USA to work at Tucson. The first stop in the journey was in Washington, DC where I gave a talk ("Pepsi and Host Stars") at Georgetown University as part of the Vatican Observatory Foundation activities. After that, I travelled to St. Louis, MO where I participated in the 234th Meeting of the American Astronomical Society, where I presented an electronic poster on the evolution of sdB stars.

I arrived in Tucson on June 15, where I spent my days doing research as well as preparing for the move to Tucson in 2020. This mostly involved acquiring, setting up, and configuring astronomy software on my new desktop computer in order to do my research.

By late July I was back in Rome, just in time to celebrate the Solemnity of St. Ignatius with my fellow Jesuit astronomers at the Vatican Observatory headquarters, the Specola. But it was only a brief stop since I then left for France to do my annual eight-day silent retreat. From France, I moved on to Vienna, Austria in mid-August to attend the astrophysics conference "Stars and their

Variability, Observed from Space". There, I presented a poster on sdB stars and recent survey missions. During August 28-30, I took part in a meeting of all the astronomers and staff of the Vatican Observatory, to assess and reflect on the mission of the Vatican Observatory.



A sample high-resolution stellar spectrum obtained using the PEPSI spectrograph (PEPSI Survey Blue Paper, Strassmeier, K., 2017).

My next port of call was again the USA, where I spent one academic semester (September - December) at St. Louis University (SLU) in St. Louis, Missouri as a visiting scholar, in the Ignatius Forum seminar, an interdisciplinary group of professors of the university, who met to discuss a particular topic. This year, it was 'Life and Death in the Cosmos'. I gave three lectures at SLU, one at Washington University, and attended the 'Science Enhances Faith' conference at Kendrick-Glennon Seminary mid-November. Moreover, I was the celebrant and homilist for the Gold Mass (for scientists) on 15 November at the seminary. Finally, I was able to give multiple lectures at St. Louis University High School, before returning to Rome on December 15.

Brother Guy Consolmagno, S.J.

Last year's report mentioned that I have been able to keep my hand on some science, working with MACKE and Fr. Cy OPEIL at Boston College on measuring and analyzing the heat capacities of meteorites. In the odd moments between my tasks as director this year I have been able to keep up on this work, which has led to one paper already published and several more in the works. Doing science is important to me; it reminds me of what the rest of the staff needs to do all the time, and it reminds me how much fun it can be and why I became a scientist in the first place!

That said, though, the majority of my year has been taken up with writing and speaking, fulfilling the charge given to the Specola nearly 130 years ago by Pope Leo XIII to "show the world" how the Church supports science.

I also mentioned in last year's report our work on Angelo Secchi. The fruit of much of that work appeared in print this year, including Ileana CHINNICI's wonderful biography of Angelo Secchi, *Decoding the Stars*, for which I had the pleasure of writing an introduction; and ongoing work with CHINNICI to edit the papers presented at her Secchi workshop last year. (I've served as translator for those papers originally written in Italian, and so I have had the pleasure of an especially intimate knowledge of that work.)

In January, I ran the fourth of our Faith and Astronomy Workshops at the Redemptorist Renewal Center at Picture Rocks outside of Tucson. Twenty-five teachers and parish educators spent a week with our astronomers and friends, seeing science first hand and talking about how it can enrich our lives — and classrooms. I also ventured into Tulsa Oklahoma to speak at Oral Roberts University, a bastion of evangelical Protestantism who gave me a wonderful welcome. We really do all live under the same skies.

February saw me travel east to speak to two Ivy League universities, Harvard and Penn; the end of the month I ventured to the University of Kentucky, the University of Dayton – where I was honored with the Marionist Award for work in science and faith – and a local Catholic parish near Wapakoneta, Ohio, the birthplace of Neil Armstrong (whom we remembered a lot this year, the 50th anniversary of his one small step on the Moon.)

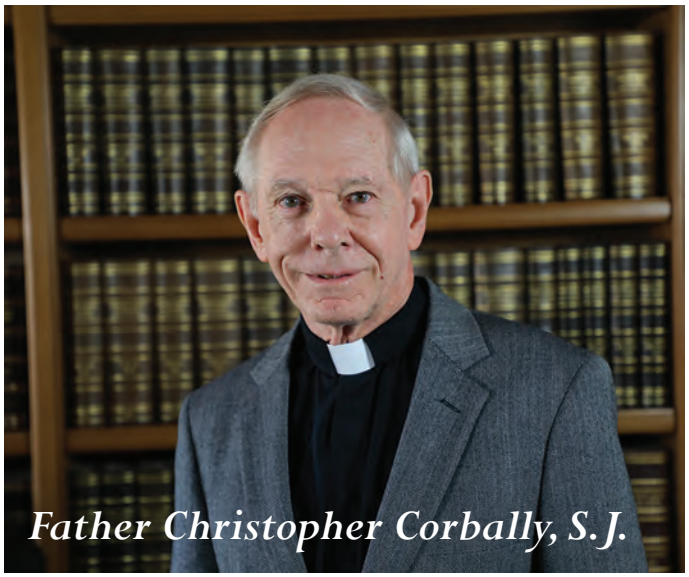
Another unexpected award came my way in March, as the Associazione Medici Cattolici Italiani (Italian Physicians Association) honored me with their 2019 "Fides et Scientia" award in Sarno, Italy. This included a wonderful visit to a part of Italy not far from the little village where my grandfather had been born, back in 1892.

April and May saw me venture to the other side of the world for a series of presentations in New Zealand and Australia. Along with meeting many wonderful members of the Catholic Enquiry Centre and Cardinal John Dew, my hosts in New Zealand, I also got to see the night sky in Lake Tekapo – a place I had first visited in 1996. That trip more than 20 years ago had inspired a new chapter on southern stars for my book with Dan Davis, *Turn Left at Orion*; Lake Tekapo is now a certified Dark Sky site and a booming astro-tourism center. Incidentally, the expanded and revised fifth edition of *Turn Left* came out in late 2018.

In June I had the honor of speaking to the graduating class of Gonzaga College High School in Washington DC. A different sort of honor came in July as I served as a guest of honor at the Convergence Science Fiction Convention in Minneapolis! Speaking of science fiction, I also was invited to speak on a number of panels at the World Science Fiction Convention held in August in Dublin, Ireland. Among my fellow panelists was the renowned astronomer Jocelyn Bell Burnell; herself an active Quaker, one of our joint appearances was to speak about how our faiths have enriched our lives of science (and vice-versa).

Rounding out the year, I also presented a series of talks in Scotland sponsored by an interdenominational program to promote science and faith, Grasping the Nettle; a talk at the Institut de Physique du Globe de Paris; and the annual Christmas Lecture in Bucharest. (And all this, mind you, was during a year in which I cut back my travel significantly compared to previous years.)

I cannot emphasize enough how welcoming all of my hosts were and how eagerly people were hearing the story of the Specola and the work we all do in promoting science and faith. Their response was a wonderful confirmation of the mission given to us by Pope Leo XIII.



Father Christopher Corbally, S.J.

The ERHE Story: Anyone who has written a book or a thesis knows the feeling. At some point, it takes over and has a life of its own. It is like the soaring of a raptor—exhilarating, along with its challenges. This certainly was the experience of my co-author, Margaret Boone Rappaport and myself as we worked this past year on *The Emergence of Religion in Human Evolution* (ERHE).

The story of this book started some six years ago when we prepared a paper to give at an International Symposium on Big History and Global Evolution in Moscow, titled *Crossing the Latest Line: The Evolution of Religious Thought as a Component of Human Sentience*. This paper seems both a long and short time ago for so much has happened since it was given. A major part of the work behind our book has been the development of our ideas through the writing of six articles for *Zygon; Journal of Religion and Science*. We remain grateful to its chief editor, Wim Drees, as he accepted one long paper after another from us, even five in one year, though two of these were solicited from us for a Festschrift. We wrote a bunch of other papers for conferences around the themes of the development and uniqueness of our moral and religious capacities. At these conferences it was helpful to air our ideas and meet interesting colleagues.

Just when we both felt that all this development of ideas was reaching a conclusion and wondered where might we go from there, I spotted an invitation from a neuroscientist, Andrew Newberg, to propose a book for the Routledge Press series that he was editing, *Studies in Neurotheology, Cognitive Science and Religion*. I had met

Andy years ago at conferences of the Institute on Religion in an Age of Science, and I much respected his work. With Andy's encouragement we submitted a proposal to Routledge in March 2018…and then waited…and waited. But we were not idle in that period for, after the prompting of a Polish philosopher we had met at a European Conference on Science and Theology, we turned to considering the development of human sentience in response to the challenges of space travel and planetary colonization, particularly on Mars. Different from ERHE, but not really in its application of interdisciplinary science!

At last, nine months later at the end of 2018, we heard back from the Routledge religion editor in Oxford, Joshua Wells. Could we answer a few questions of reviewers and resubmit our proposal? Of course, so we dropped "Mars" for a while, responded to the editor's concerns, and were rewarded by being offered a contract to submit a manuscript by the end of July 2019. Given other writing commitments, we pushed this deadline back a month, and duly signed the contract last January. Rappaport is a speed writer, if not a speed reader, and the Preface started rolling off her keyboard (pens have been supplanted for a good while) at the end of February.

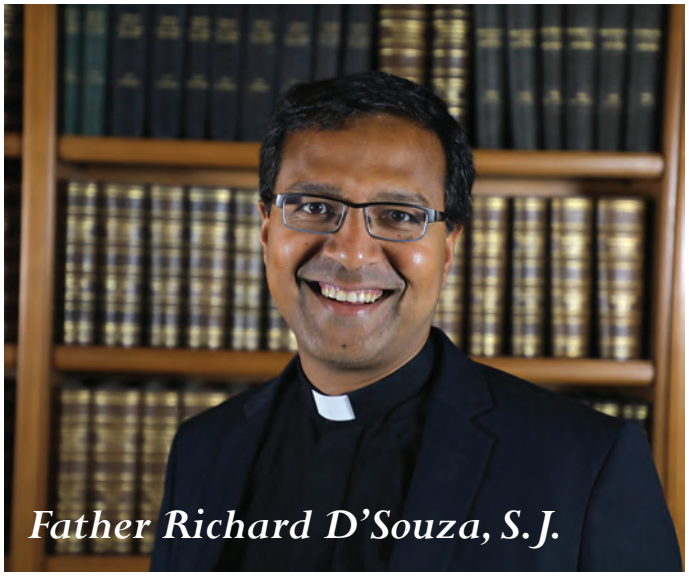
It was then that the book took over. The idea crystallized that what made for human survival also gave us the capacity first for morality and then religion; and the draft was finished two-and-a-half months later. Much checking, rearranging material, and polishing followed in early summer. To top the creative pyramid, we realized that the book fell naturally into three parts: Introduction to Theory, The Model, and The Implications; and we submitted the manuscript just before the original deadline, end of July.

Our apprehensions over whether it would be accepted were relieved by finding the book appearing for pre-orders, and we were delighted to be invited to give a talk in early October, sponsored by the Institute on Religion and Science at Chestnut Hill College. There we duly sketched the outlines of the book's hypothesis and answered stimulating questions. A number of the audience confirmed their pre-orders of the book. Thus encouraged, we have been busy with the copy-edited version, the proof pages, and populating the index, all familiar tasks for writers. These all got swiftly into the hands of Routledge, who made good on the schedule, and indeed the book was ready as a Christmas stocking stuffer.

What follows? This book is somewhat a challenge to read, combining as it does research from nine scientific disciplines. But many friends, on hearing the title from me, found the topic fascinating, as well as reassuring. Their religion, while reaching to the supernatural, is natural, for it is grounded in our evolutionary biology and culture. So, they called for a popular book to present the new ideas behind all this. Now, thanks to Rappaport's ability to write novels (and plays, and poetry), two of the *Zygon* articles already contain a *Story of Bo*. Let us then write more such stories illustrating ERHE's ideas, and include explanations in a non-academic style. We just have to find a publisher for that book too!

Stellar Topics

I have not neglected investigating intriguing stars either. An early-February observing run at VATT brought a little progress for Young Solar Analogues, but like other observing this year it suffered poor weather and so only the bare minimum of data resulted. I also supported Eric Craine (Western Research Company) and Roy Tucker (Goodricke-Pigott Observatory) in obtaining short cadence spectra at VATT of the variable object, currently known as MG1-xyz432. This has extensive photometric documentation of its energetic outbursts, but just whether these are caused by a single or multiple star system has not been clear. The VATT spectroscopic data are contributing towards a defensible model for the outburst activity.



Father Richard D'Souza, S.J.

2019 could be described as a year of transition. Not only did I make the transition from Michigan to Rome in June, trying to learn a new language along the way, but

I also transitioned to working in a new but related field. For the last couple of years, I have been studying the past merger histories of nearby Milky Way-like galaxies through their low outer surface brightness regions, called stellar haloes, which are built up from the debris of destroyed satellites galaxies. This year, I turned my attention to studying the existing satellite galaxies of nearby Milky Way-mass galaxies.

This transition is timely! Some of the biggest problems in astronomy today are found at the scales of dwarf galaxies, revealing problems in our present models of dark matter. Thanks to new observations and techniques developed in the last 15 years, we have gotten better at discovering dwarf galaxies around the Milky Way, Andromeda (M31), M81 as well as other nearby similar-sized galaxies. However, the number and properties of these dwarf galaxies pose a number of challenges to our existing understanding of how dark matter clumps into halos and subhalos at these small scales. The problems associated with dwarf galaxies is one of the most exciting problems in astronomy today!

A big lacuna in this field is that people assume that the Milky Way and M31, around which dwarf satellites are being discovered, are typical galaxies for their masses, without any consideration for their different merger histories. In comparison to the past, today we have a much better idea of the merger histories of the Milky way and M31. Today, thanks to data from the Gaia satellite as well as other spectroscopic surveys like APOGEE, RAVE, LAMOST, etc., we now know that the Milky Way accreted a large galaxy (of about the size of the Small Magellanic Cloud ~10 Gyr ago). By studying the stellar halo of the Andromeda galaxy, I have demonstrated that M31 accreted a large galaxy half the size of the Milky Way ~2 Gyr ago. Such large accretion events must have surely contributed a number of their own satellites to the existing satellite populations of the Milky Way and M31. With a better insight into the merger histories of these galaxies, we are now in a better stage to understand which properties of the satellite populations of nearby Milky Way-mass galaxies should encode their merger histories.

With this paradigm in mind, my collaborators and I started exploring various hypothesis about which properties of the satellite populations of M31 and the Milky Way would give us the best handle on their merger histories. Unfortunately, many of our initial ideas turned out to be plain wrong. Alas, this is how science is done! Research in science is not only about success, but also of the many wrong ideas and null results obtained along the way. Was the year wasted? Not at all, we surely did learn a lot: we now know what works, and what does not! And we have a pretty good sense of which directions we now need to explore in the future. Additionally, new data made public in August of this year seem to confirm our new ideas. We hope that our explorations in the coming year will bring many new interesting insights and discoveries!

Father Pavel Gabor, S.J.

One of my primary responsibilities as Vatican Observatory's Vice Director in Tucson is the Vatican Advanced Technology Telescope (VATT). The VATT is a joint project with the University of Arizona. In 2018, important changes took place in the organization of this project. Steward Observatory's Mountain Operations group has a new management structure. I refer you to the chapter on Instrumentation and Technical Services for particulars. As a part of this process, Buell Jannuzi, Steward's Director, created a Science Advisory Committee (SAC) for small and medium-size telescopes, and asked me to serve on it.

SAC's first order of business is to outline where we want to be in the mid- and long-term horizon. Our discussions have confirmed my conviction that 2-meter class telescopes have a crucial place to play in the next few decades. Over the years, astronomy has opened a number of windows on the Universe.

Astronomy has been conducted for millennia in visible light. During the course of the 20th century we widened the wavelength range window to its maximum. It now spans radio waves, microwaves, infrared light, visible light, ultraviolet light, X rays, and gamma rays. New techniques have given us access to more and more profound knowledge, be it adaptive optics, high angular resolution, spectroscopy, radial velocities, etc. The first two decades of the 21st century have already seen three major new developments in observational astrophysics: cosmic rays (high energy astrophysics), gravitational waves, and time domain astronomy (TDA).

When a supernova is detected by the Zwicky Transient Facility, for example, other telescopes are needed to pursue follow-up photometric and spectroscopic observations over several months (this is TDA). It is similar with gravitational wave event, and many other fast astrophysical phenomena. TDA thus goes hand in hand with Multimessenger Astrophysics.

In this context, the VATT together with other telescopes of its size can be on the cutting edge of scientific discovery, but it must be able to react swiftly. Its operation must be at least scriptable (running a series of tasks from a script, preferably without a human service operator). Consequently, time allocation on the VATT must move away from allocating whole sets of nights to a single project. To this end, VATT upgrades continue. I believe that as we move along this path, the VATT can take on an increasing number of projects and make significant contributions to astrophysics.

The research projects I am involved in are proceeding at good pace. I have described the VATT-PEPSI-TESS survey in the 2017 Annual Report, and the EDEN Transit Survey in the 2018 Annual Report. Vatican Observatory headquarters at the Papal Residence of Castel Gandolfo hosted the first full team meeting for the VATT-PEPSI-TESS survey (see chapter on Visitors).

I have taken part in the first two meetings of the nascent Alliance of Historical Observatories. The first was on Mt Wilson, June 15 to 16, and the second at Mt Palomar, September 19 to 20. I found it encouraging. Sandra Faber (Lick Observatory) spoke the role observatories played in humanity's "coming of age in the Milky Way." These are the places where we opened the book of the Universe. Ed Krupp (Griffith Observatory) shared his deep conviction that when members of the public visit an observatory, it is not just to gain information but rather it is more like a pilgrimage to a site sacred to our civilization's story. A telescope dome is like a cathedral of science. That is why we drafted this mission statement:

"Historic observatories are where our eyes were opened to the vastness of the cosmos and our connection to it. The Alliance of Historic Observatories preserves and promotes their enduring power to orient and inspire us on our journey into the future."

Whenever I hear my colleagues share on this level, I see it as a confirmation that reading the Book of Creation (conf. Rom 1:20) naturally leads to the impression that we are unthinkably blessed.

Father Gabriele Gionti, S.J.

2019 was a year of travel, for science, science and theology and of popular talks. I had not been to Tucson in almost four years, so after my visit to Georgetown University I went to see my Jesuit brothers at the Vatican Observatory there. This gave me the opportunity to see the Steward Observatory and even do some work.

On my return to Italy, I went to Catania to discuss Dirac's Constraint analysis of the Brans-Dicke theory with Alfio Bonanno. Then, after my spiritual exercises, I participated in the Field and Gravity Group (FLAG) meeting at the Italian National Institute of Nuclear Physics (INFN) at

the Physics Department of the University of Bologna. I presented on Quantum Path Integral Measure in Regge Calculus, an area of research I want to resuscitate (it has been on hold since my first post-doc in UC Irvine).

The "big" event in the first half of the year was visiting Prof. Martin Reuter and his group at the Theoretical Physics Department of Mainz University, Germany. We had a pleasant series of informal talks on deepening our understanding of the Asymptotic Safety approach to Quantum Gravity (mainly started by Reuter) and to discuss my research. Interestingly enough, at the time I was writing an article on proceedings from the 2018 Castiglioncello Convention and these discussions helped to greatly improve the introductory part on Asymptotic Safety.

Being in Mainz also gave me the opportunity to pray before the famous crucifix St. Peter Fabre, S.J. Moreover, while I was there I received an e-mail from my provincial that I had been admitted to final vows. It was an immense joy and a real boost to continue in my activities.

Once back at the Specola, I finished my paper and continued to think and work on the problem of constraint analysis of Brans-Dicke, although something was still missing from the overall picture. I felt the research wasn't finished. Then the Korean Institute for Advanced Science (KIAS) invited me to for a visit, so I flew to Seoul. It was during a seminar on my research on Brans-Dicke that I found a mistake in my calculations. This discovery was crucial. Although the improved calculation did not conceptually alter the result, it did help me understand that one that something I had been assuming was wrong.

In March, I went to Avila, Spain, as keynote speaker at a workshop titled "A new cosmological view of the Universe and the awareness of the Sacred". It was organized by the CITES, University of the Mystics, a group of lay people of Carmelite Spirituality. Back from Spain, I concentrated on ongoing collaborative projects with Alfio Bonanno. We are also continuing our research with Matteo GALAVERNI on "Chiral Anomaly in Curved Backgrounds". The problem is that because of curved backgrounds the "quantum oscillations" of the Maxwell field in a curved background break the (Chiral)-symmetry that solutions of Maxwell Equations have. As a result of this, a source of light passing either two coalescing Neutron Stars or (Kerr) Black Holes should have a number of left photon that is different from the right photon. Therefore, in principle, there should be a (quantum) electromagnetic counterpart, although quite small for quantum reasons, to the gravitational wave detection of two coalescing massive bodies. This research has some technical problems which need still to be understood and we hope, in the near future, to understand them.

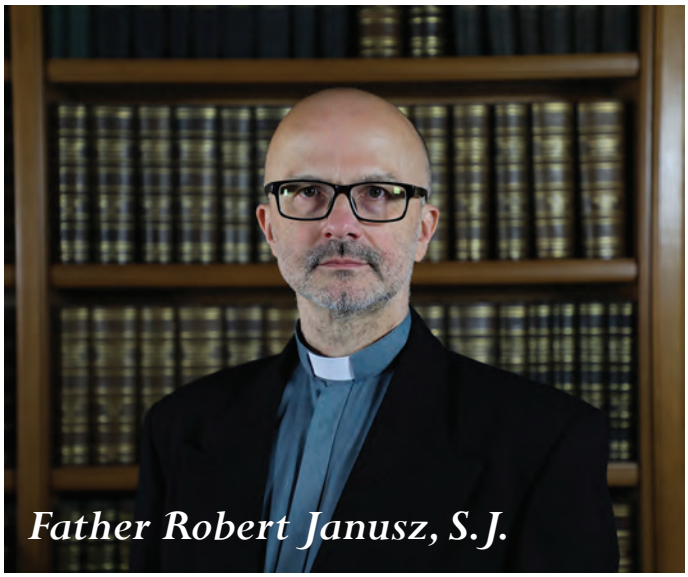
Around Easter, Fr. Nelson Velandia, S.J. professor at Javeriana University in Bogotà, Colombia, visited the Specola for a research project with Donato Bini and Andrea Geralico of CNR in Rome. The idea was to develop a joint project on the classical trajectories of uncharged particles scattered by a binary system consisting of extremely charged black holes in equilibrium as described by the Majumdar-Papapetrou solution. We have heard that the paper has been accepted and will be published soon.

This year I also hosted Dr. Paolo Beltrame an Italian novice of the British province for a six-week Ignatian "experiment" in science at the Specola. Paolo is an experimental particle physicist who has worked in Dark Matter. The idea for this science project came to me during a discussion with Danilo Babusci of INFN's National Laboratories of Frascati (LNF). Danilo proposed that Paolo could collaborate in the "KLASH" experiment in Dark Matter in Frascati. At the end of the six weeks Paolo was very happy with this experience and "unique" opportunity. He even signed the report paper on the experiment which appears in the electronic archives ArXiv.org (*https://arxiv.org/pdf/1911.02427.pdf*).

On June 29, the feast of Saint Peter and Paul, patrons of Rome, I pronounced my final vows in the St. Ignatius Church in Rome. I chose this church because it is a symbol of the scientific tradition of the Jesuit Order. Fr. General Arturo Sosa, S.J. received my final vows in a moving ceremony. It was a beautiful and emotional moment in my religious life to have friends and family gathered around me, in the very place where over 100 years ago Fr. Angelo Secchi S.J. built his telescope to contemplate the cosmos.

After two popular talks, one at the Aeronautical Engineering Department of Vanvitelli University in Aversa (CE) and the other in Milan, EURESIS Center, I went to Catania to a conference in which I presented a finally improved version of my Brans-Dicke Dirac's constraint analysis from which it has emerged an inequivalence, at the Hamiltonian level, between the Einstein Frame and the Jordan Frame. These frames are related by "Weyl" transformation of the metric tensor. This seminar was accepted and repeated at the General Relativity and Gravitation International Conference in Valencia-Spain, at SuperVoss-2019 in Castel Gandolfo , at a popular level, but also at the Conference "Quantum Gravity and Matter" in Heidelberg, Germany, a conference organized by the Asymptotic Safety people community whom I belong.

On September 27-28 I participated as a plenary speakers to the Conference "Creatio ex nihilo": New perspective from Physics, Theology and Philosophy organized by Korean Catholic Society in Seoul, South Korea. I gave a talk "Contemporary Cosmology and Creatio ex Nihilo". It was a very nice conference with a lot of challenging discussions on Science and Theology. The rest of the time until October 7th I was hosted at KIAS by Prof. Jaewan Kim.



Father Robert Janusz, S.J.

This year was my last year spent in Poland, where for the past twenty years I have mainly worked at the Ignatianum University in Kraków and Michael HELLER's Center for Interdisciplinary Studies. But throughout these years I have also been collaborating with BOYLE.

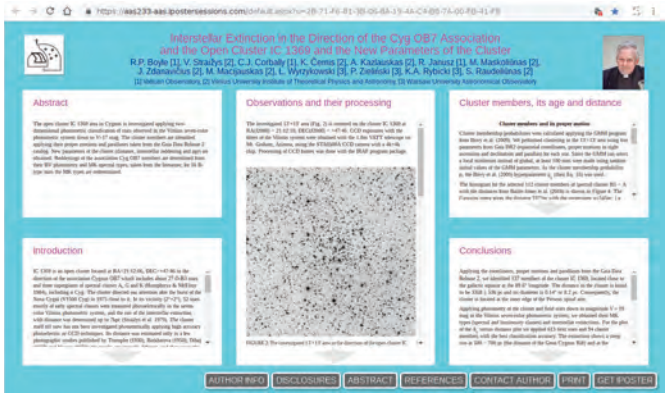
It all began in 1998 when, after finishing my theology studies in Italy, I visited the Specola for the first time. During that visit Fr. Sabino Maffeo introduced me to its then director, Fr. George V. Coyne, who invited me to take part in the Vatican Observatory Summer School in the summer of 1999.

This resulted in my being included in the analysis of the Vatican Advanced Technology Telescope data project. I went on to spend some time in Tucson and on VATT / Flagstaff observations, as well. In 2005, I was appointed an Adjunct Scholar by Coyne and over the following 20 years, BOYLE and I created an outstanding team at the Specola, with an excellent collaboration with other astronomers, mainly from Lithuania.

Then this year to my delight, the current director Guy CONSOLMAGNO invited me to come on board at the Specola full time, with my superior's permission. Thus as of September 1st I am honored to officially be a staff member of the Vatican Observatory.

BOYLE and I have a lovely office at the Rome headquarters, where I plan to make some kind of "museum" of various techniques used here in photometry. Of course, the VATT repository of all scientific data will be its core. I hope to present something on the theoretical importance of a photometric system and the key people with whom the Specola collaborates in stellar photometry.

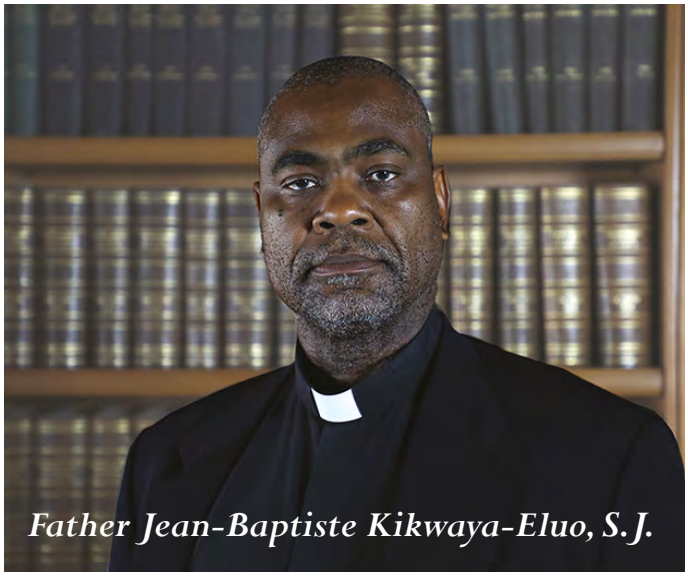
Besides other studies carried out at the Ignatianum, this year I also lectured on science and religion and was on the organizing committee of the 22nd Kraków Methodological Conference (*http://22kmc.copernicuscenter.edu.pl/*), organized by HELLER's Copernicus Center in Kraków. While still an adjunct scholar BOYLE and I did a workshop



Poster paper on CYG OB7

in Castel Gandolfo on stellar clusters. It was an enjoyable experience to participate in the Super-VOSS 2019 and see how various projects are evolving.

In September BOYLE and I went to Vilnius for a workshop, where we also had the possibility to visit Kaunas Jesuit School and present to them on the Specola's activity. Once settled back at the Specola, I now have sufficient time to work on the repository of VATT data, the archive, elaboration of photometrical data, improvements of my software, and participate in Internet seminars with Lithuanian astronomers.



Father Jean-Baptiste Kikwaya-Eluo, S.J.

While continuing my work on Neos, this year I began thinking about exploring the field of meteors and Comets. We already have a system of three all-cameras recording fireballs brighter than 3 magnitudes around Tucson. In February, the Vatican Observatory will join Fripon, a system of all-sky cameras in France and Italy run by the Paris Observatory which are recording fireballs brighter than the apparent magnitudes of -3.

But primarily, I want to address the question of the dialogue between science and faith. Is there a right way to talk about it, to present it, and to conduct a discussion about it? All I know is that in the debate between science and faith, we try to reconcile two ways in which we attempt to relate ourselves to reality (to whatever surrounds us). Thus they appear as two separate cultures. And I know that in the tradition of the Church, dialogue with cultures is at the heart of evangelization. In order not to reach back as far as St Paul in his dealings with the Greeks and others, I would point to the work of Justin, Irenaeus, Origen, Augustine, the so called "Fathers" we study in the branch of theology called Patristics or Patrology. The "Fathers" were approaching cultures with one idea: get into dialogue (conversation) with them.

Dialogue with cultures appeared to be set apart (forgotten) during the Middle Ages. The political power of the Church put the Gospel in a situation where it was not what was engaging cultures in dialogue, but instead it was imposed on them, just like setting a stone on the top of a structure without allowing it to be formed by it. In this context, dialogue with science could only become difficult in general, but not in private efforts and initiatives. The same as other cultures, science felt oppressed, misunderstood, and somehow feared. It grew suspicious.

Science would take its revenge during the Age of Enlightenment (modernism). The Church stood accused of obscurantism, even of being against science. We could say it was now the turn of science to raise itself up, with a certain degree of arrogance, and also arouse a romantic attachment to it. People started to fall "in love" with science.

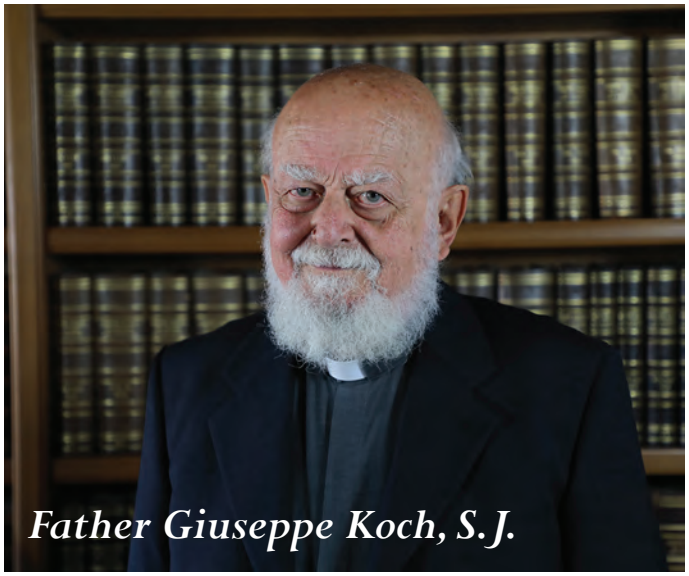
This new situation forced the Church, caught unawares, to readjust and almost play catch up with science. The Church adopted an apologetic tone in its discourse on science. On March 14, 1891 Pope Leo XIII issued the *motu proprio* "Ut mysticam" refunding the Vatican Observatory (the actual foundation of the Vatican Observatory coincides with the effort of the Pope Gregory XIII to reform the calendar in 1582). He wanted to show and assure the world that the Church by any means was not against science. For the Vatican II, faith and science are not incompatible, but instead are two ways to approach the world (NOMA of Jay Gould). The general move was then to consider the debate of science and faith in the general context of dialogue between cultures (back to "Fathers"), a tendency pushed and encouraged during the Council by French Jesuit Theologians: Danielou, Lubac, Joseph Moingt.

How should we talk then about the dialogue between science and faith, or mostly between science and religion? We can think of three different approaches. The first approach would be a historical one. Here, the goal is to show how each of these two components are constructed through time. Paradigms and models on what science is fundamentally based on are constructed, deconstructed,

modified, improved, … This image of work always in progress, or marching toward something is what we find both in religion and also in science. The second approach is epistemological. Against the romantic vision of science, we need to state that science is not a pure reflection of reality. We also need to bring in here what Michael Polanyi called tacit knowledge. This means that what is said, or put forward as confirmation, result, is always less than the totality of the experience when conducting science that lead us to that result. And this is also true about the other component of the dialogue (faith). It is not about what we want to know (reality, someone, or God himself)- the object of the knowledge, that won't be totally known, but it is about the experience of the knowledge itself. This golden mine of our knowledge (the experience gained while trying to know something) is where we all meet (scientists, theologians, engineers, mothers, fathers, human beings, …). Here, we only experience all the humility of life. Arrogance comes with what we think to be the results of our research (whatever that research could be) and we want to impose on others, and be recognized by them. When a scientist has understood where the discipline he is conducting resides (it is more in the process of doing it than in the results it produces), then he can engage himself in the third approach to dialogue between science and faith (or science and religion), the testimony approach. Teilhard de Chardin is the best example of this. We can apply and develop this approach in our encounters with our scientist colleagues and in our desire to work on the dialogue between science and faith (science and religion).

African priests working in the diocese of Tucson visit the VATT hosted by Fr. Kikwaya-Eluo and Fr. Boyle

On Easter Tuesday April 23, 2019, the African priests working in the diocese of Tucson (23 in total) held our meeting in Safford, just one hour away from the Vatican Advanced Technology Telescope (VATT). I took that opportunity to bring all of them to Mount Graham to visit the telescope and explain the churches' work in science, particularly astronomy to them (see pictures).

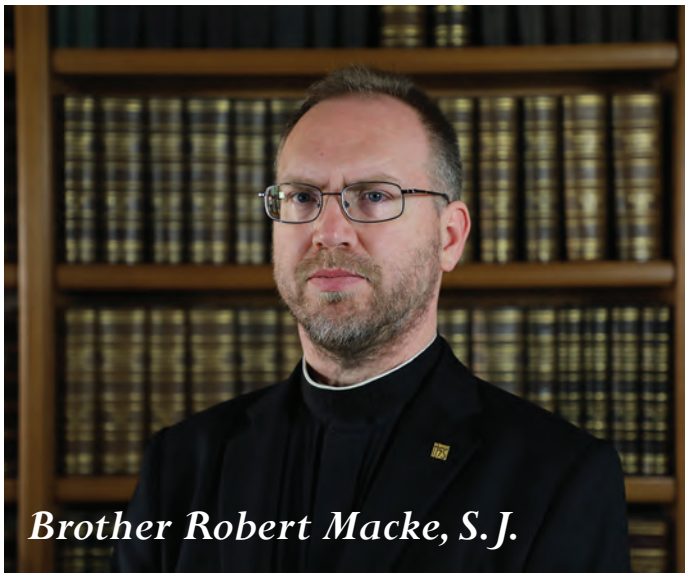


Father Giuseppe Koch, S.J.

The cataloging of ancient books or of special historical interest for astronomy is in progress. For the time being more than 300 volumes have been cataloged. Three of them date back to the 1500s: the oldest of these is from 1560, another notable one is from *Clavius* from 1588. There are then forty books from the 1600s including works by Copernicus, Kepler, Descartes, Riccioli, Kircher, Scheiner, by Ticho Brahe and Galileo's *Systema Cosmicum* from 1699. We have many volumes dating from 1700 onwards.

Among the rarest publications we can mention two, one on the annual Parallax of Vega and the second on the Solar Eclipse of February 1804 by Giuseppe Calandrelli, who was the director of the Observatory of the Collegio Romano in the years of the Jesuits' suppression.

Among the ancient material present at the Specola we must not forget some famous collections such as the more than one hundred volumes of the Philosophical Transactions beginning from 1665 until 1802, or the collections of many ancient Academies, for example the Astronomisches Jahrbuch or the De Bononiensi Scientiarum et Artium Instituto atque Academia Commentarii: series that both began in the 1700s.



Brother Robert Macke, S.J.

This has been a fairly busy year. I started with my annual trip to Tucson. I like to try to get there before the annual Tucson Gem and Mineral Show, when the entire city becomes a marketplace of rocks, minerals, fossils, and (of course) meteorites. It is a chance to meet with other meteorite collectors and dealers, and to acquire a few new meteorites for the Vatican collection.

A paper on the subject of meteorite heat capacities that I had been working on was finally published this year. Collaborators Guy Consolmagno, Cy Opeil, and I combine different techniques for measuring meteorite heat capacity of ordinary chondrites at low temperatures, showing that they produce compatible and complemental results.

Speaking of Cy Opeil, he and I continue to collaborate on thermal properties of meteorites. Recently his student Matthew Bonidie presented their latest research on thermal properties of iron meteorites at the annual American Physical Society March Meeting in Boston. On my way back to the Castel Gandolfo from Tucson, I passed through Boston for the meeting to hear his talk, on which I was a coauthor.

Most of the summer was occupied by various research collaborations. I have developed a reputation as an expert in measuring density and porosity of meteorites, so people send me their specimens for this measurement. This includes ongoing collaborations with George Flynn (SUNY Platsburg), Melissa Strait (Alma College), and Dan Durda (Southwest Research Institute); and Jon Friedrich (Fordham U) and Alex Ruzicka (Portland State U). In addition, last fall Cyrena Goodrich (Lunar and Planetary Institute) sent me a tiny piece of Almahata Sitta. It would not have been possible to measure this 195 mg specimen without the use of our 3d laser scanner, along with a custom-designed meteorite mount made by our 3d printer, which we acquired in the fall of 2018. Further new collaborations this year include David Capek (ASCR, Czech Republic), Alexandra Ahern and Deanne Rogers (Stony Brook U).

I am also considering the study of meteors, meteoroids, and bolides. I was asked to contribute part of a chapter in the edited volume Meteoroids: Sources of Meteors on Earth and Beyond, which was published this year, and this has prompted me to look for other ways to contribute to this field of research. With this in mind, I attended the 10th Meteoroids meeting in Bratislava, Slovakia.

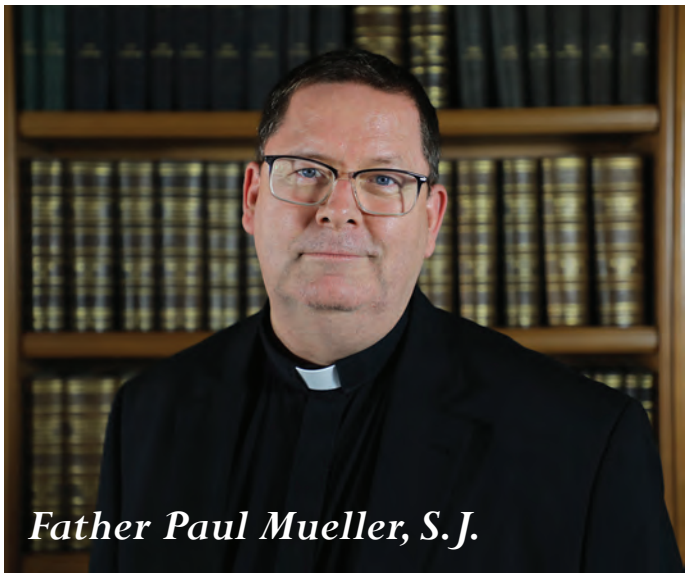
Outside of research, I have added two new columns to my contributions for the Sacred Space Astronomy blog. Every week I highlight one notable person who has signed the guest book of the Vatican Observatory in a column entitled "Specola Guestbook." Once a month, I write about a priest or vowed religious who has made a significant contribution to science in the column, "Religious Scientists."

This year I fielded a few interviews regarding the 50th anniversary of the Apollo 11 mission. These interviews were used in articles published in (among others) America magazine and the Catholic News Service. In addition, for our in-house celebration of the event, I set up a display of all of the various Apollo-related artifacts and memorabilia of the Specola (including the moon rock from Apollo 17).

I write this from Portland, Oregon, where I have been since September. I am currently undergoing the last stage of Jesuit formation, known as tertianship. During this nine-month period, we reconnect with the roots of the Jesuit charism. It involves study of the Jesuit Constitutions, the full 30-day silent retreat known as the Spiritual Exercises, and various other "experiments" designed to rekindle the flame of our vocations and challenge us in new ways. I will return to the Specola at the end of May.

Brother Bob at one of the sites of the Tucson Gem & Mineral show.

Display of Apollo-related artifacts at the Vatican Observatory. Examples of items on display include: "Moon rise" photograph from Apollo 8, signed by Frank Borman; Photo of Eugene Cernan on the moon during Apollo 17, signed by Cernan and his wife, addressed to Pope Paul VI; moon rock from Apollo 17 along with a Vatican flag that flew on the mission; piece of a "moon tree" that grew from a seed flown on Apollo 14; two lunar globes from the Apollo era; photographs of Pope Paul VI watching the Apollo 11 landing from our telescope domes; and several models of Apollo spacecraft.



Father Paul Mueller, S.J.

Since travel between Tucson and Rome is expensive, and since the schedules of Observatory staff members tend to be full and complicated, it's not often that the whole staff can come together, at the same place and time. So the high-point of the year for me was when whole staff was together at Castel Gandolfo for several days at the end of August. We began on Tuesday evening by praying at the Eucharist, with GIONTI presiding, and then we enjoyed a grill-out on the terrace of the Jesuit residence. Wednesday was given over to prayer and discussion concerning the state of the Observatory and its future; in this we were joined by our Jesuit major superior, Fr. Juan Antonio Guerrero Alves S.J., who also presided at the Eucharist. (Fr. Guerrero Alves has since been named as Prefect of the Vatican Secretariat for the Economy.) On Thursday our focus shifted to how we can best engage the public on questions pertaining to the relationship of faith and science; we were assisted by Prof. Chris Baglow, Director of the Faith-Science Initiative at Notre Dame University. That afternoon CORBALLY presided at Eucharist, and then the group moved on to Bucci restaurant at Castel Gandolfo, where we enjoyed a convivial dinner with a view from on high over Lake Albano.

On Friday we were received in audience by Pope Francis in his private library. For me and for others, it was deeply moving to have this very personal confirmation that the Observatory exists and works at the service of the Church and Holy See. After we returned to Castel Gandolfo that afternoon, I presided at the Eucharist and then we enjoyed pizza together on the terrace. As superior of the Jesuit community of the Observatory, I

am very grateful for our time together during those three days, which deepened and fortified our commitment to each other, to the Church, and to our mission.

The Holy Father, Pope Francis, with Specola staff at the end of a private, informal audience in the papal library.

During the spring semester I taught a masters-level course at the Pontifical Gregorian University at Rome, "Philosophical Questions in Physics". My students were an international group of young priests, sisters, and lay people, with some spice and experience added by two older professionals who wanted to audit the course. I love my work at the Observatory, but I also very much appreciate this opportunity to go into Rome and interact with students on a topic of great interest to me, the philosophy of physics. For me it remains a challenge to teach in Italian. But I find that my students are patient and appreciative, especially since they too often are struggling to master that beautiful but difficult language. I look forward to teaching another course at the Gregorian University in spring of 2020, "Philosophical Questions in Biology".

Since I'm the Observatory's vice director at Rome, as well as superior of the Observatory's Jesuit community, the bulk of my time and effort go into sharing the daily concerns of our lay staff and Jesuits, and to interacting with our Vatican colleagues. For me it is a consolation and pleasure to be of service in this way.

Father Alessandro Omizzolo

The composition of the Universe as described by the currently accepted model seems to consist of three main elements: ordinary matter (or baryonic matter), dark matter and dark energy. The percentages are 4% for the first, 27% for the second and 69% for the third (at least these are the data after the exploration of the Planck satellite) *(Fig. 1)*. The baryonic matter constitutes the matter that we can also see and that emits electromagnetic radiation in the form of visible light and also any other radiation (X-rays, gamma, radio waves, ultraviolet rays, infrared rays, microwaves); we see this and we can study it with telescopes sensitive to various wavelengths both from the Earth and from Space *(Fig. 2)*.

We do not know what dark energy is but we assume that it is responsible for the accelerated expansion of the universe for about 5 billion years and its future behavior (linear or accelerated increase, decrease) will determine the future of the universe.

However, we are beginning to understand a little more about dark matter, particularly its composition, and we can also see and measure its effects, especially in the vicinity of large mass agglomerates such as galaxies and galaxy clusters. The first method used to discover this was the study of the rotation curve of the galaxies: there was an evident discrepancy in the comparison between model and observations which argued in favor of the fact that there was an invisible mass capable of determining the motion of the stars within a galaxy *(Fig. 3)*. The presence of dark matter seems to set things straight and explain the observed rotation curve.

Another place to study the properties of dark matter is given by the clusters of galaxies that are immersed in huge halos of dark matter that determines the balance and internal dynamics of the cluster. If we now look at space as Einstein taught us through general relativity, we know that the large masses deform the surrounding space-time, thus also forcing the electromagnetic radiation to move no longer in a straight line but following curvilinear trajectories whose curvature is determined by the "quantity" of dark matter present.

In galaxy clusters the majority of the present matter is in the form of dark matter and therefore we must expect many curved light paths. And indeed if we look at any image of a cluster of galaxies we see images that are either deformed or in the form of arcs and circles due precisely to the presence of dark matter. The phenomenon is known as a gravitational lens *(Fig. 4)* and means that these large amounts of dark matter are able to focus images of distant objects that otherwise we would not be able to see. Obviously the mass of a galaxy alone can generate these effects but in galaxy clusters they are much more evident *(Fig. 5)*.

I was studying a cluster of galaxies (RXCJ2211-15) *(Fig. 6)* on images obtained with the Hubble telescope for the RELICS (Reionization Lensing Cluster Survey) project searching for Jellyfish galaxies, when I came across a strange image of a galaxy located at the edge of the cluster and surrounded by four bright spots of blue color arranged in the shape of a cross around the galaxy. The appearance left no doubt: it was a particular type of gravitational lens known as "Einstein's Cross". The galaxy that acts as a lens is located near the cluster RXCJ2211-15, which is located at a distance of 3.2 billion light years in the direction of the constellation of Aquarius, but is further away from it (it has a greater redshift). However, the object of the image in the form of a cross is a great deal more distant, therefore it is a primordial but still very intense object to be visible at such a great distance despite the effect of a gravitational lens.

In order to be certain that it is indeed a gravitational lens that allows us to see a distant object, we had to establish the distance of the source of the four images. But to do this we needed the spectrum of these images. Using the Canarias Gran Telescope, we obtained the spectrum of three of the four blue images allowing us to establish that this is not a distant quasar but a distant Lyman-type galaxy break with great star formation activity. This is the second known example of this type of lens *(Fig. 7 and Fig. 8)*.

The study of these objects confirms the validity of the general theory of relativity that had predicted its existence and it is also useful, as already mentioned, for the study of the distribution of dark matter in the universe. It also helps us to independently derive some important cosmological parameters, such as the Hubble constant, by other methods. To learn more about the geometry of the lens, we built a model of the galaxy-lens system that highlights the combined effect of the galaxy and the cluster in generating the geometric arrangement of the 4 images of the lens as well as the different magnification of the images themselves *(Fig. 9)*.

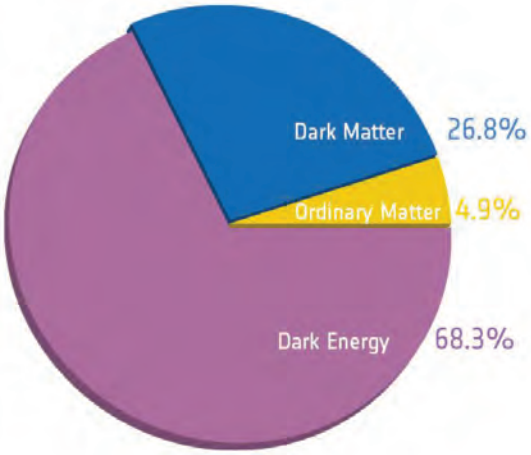


Fig. 1

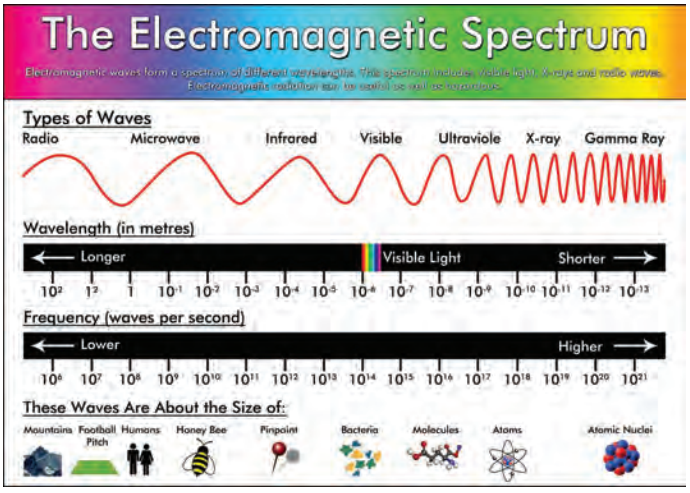


Fig. 2

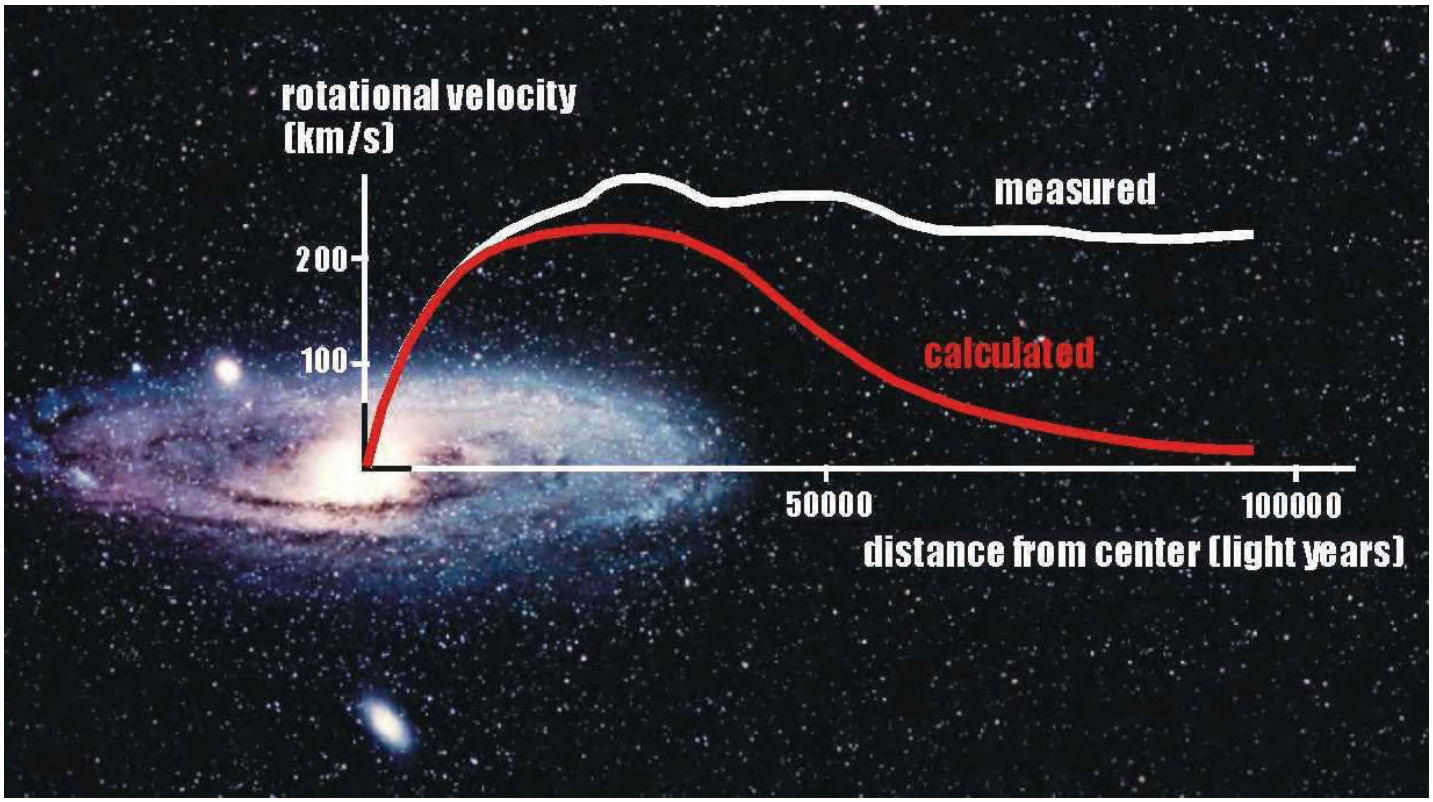

rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)

Fig. 3

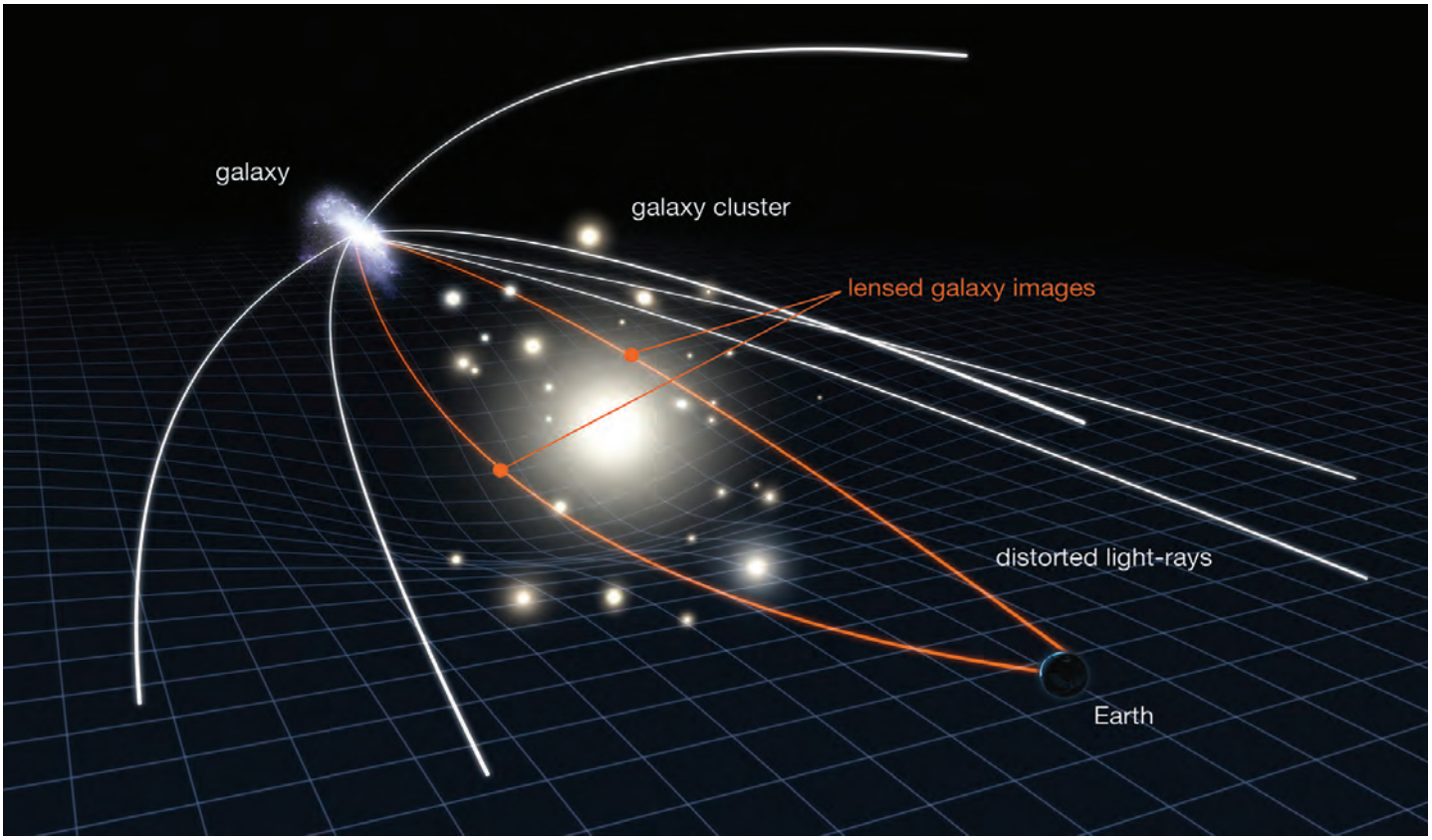

galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

Fig. 4

Fig. 5

Fig. 6

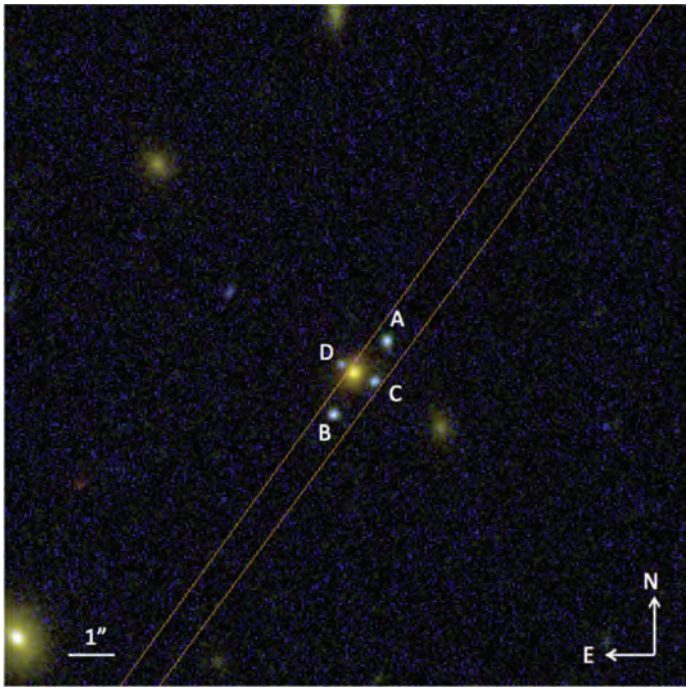


Fig. 7

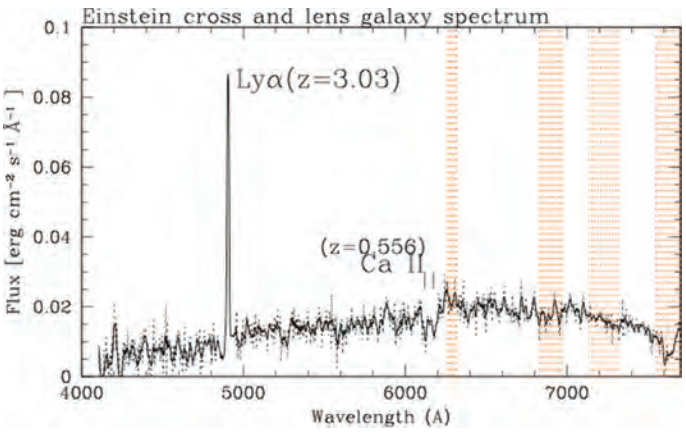
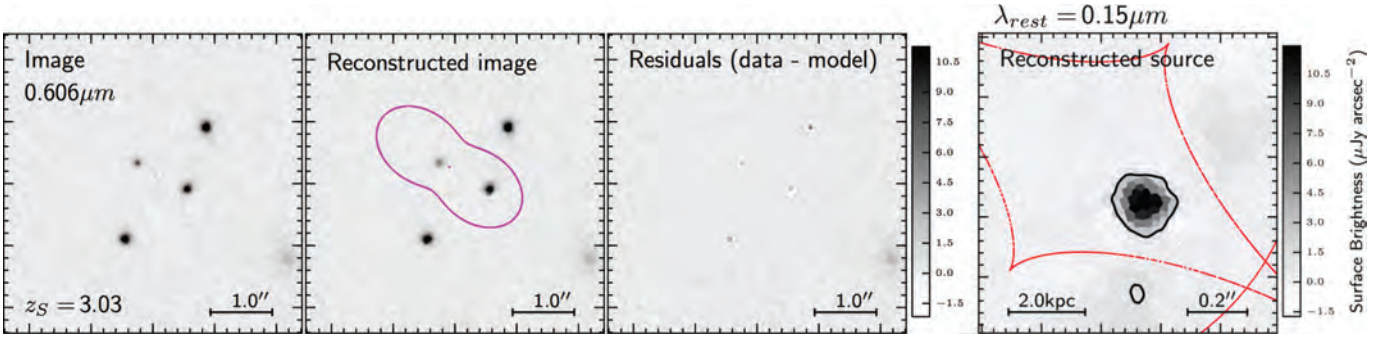


Fig. 8

Fig. 9



ADJUNCT SCHOLARS

Aldo ALTAMORE

My work at the Vatican Observatory is mainly centered on the study of the history of astronomy, particularly the history of astrophysics in Rome from the mid XIX century to the present time.

Specola staff visit Rome's Astronomical Observatory in Monte Porzio Catone.

In this framework and as a member of the National Committee of the Italian Ministry for Cultural Heritage, I was involved in events commemorating the bicentenary of the birth of Jesuit astronomer Angelo Secchi (1818-1878) in 2018, some of which spilled over into 2019. The activities I helped to organize were addressed to scientists, students and to the wider public in Rome, Palermo, Reggio Emilia and Padua, promoted by Accademia dei Quaranta and the Italian National Institute of Astrophysics (INAF).

In June I was happy to act as guide for the staff of Vatican Observatory who visited Rome's Astronomical Observatory in Monte Porzio Catone, where astronomical and magnetic instruments used by Secchi are on display.

I am also involved in the working group for the restauration of Collegio Romano Observatory which is promoted by Rome's Office for Public Heritage Works, the *Soprintendenza Speciale di Roma Archeologia Belle Arti e Paesaggio*.

I collaboration with MACKE, I investigated the nature of a meteorite that weighs about 6,5 kg which is kept at Collegio Romano in the CREA meteorological library. I took also part in the general internal discussions on communicating science as part of the Vatican Observatory's future projects in the field of outreach and education.

I continued to pursue projects on teaching and communicating physics and astronomy in collaboration math and physics department at Roma Tre University, where I taught until my retirement. Part of this outreach is training physics and natural sciences teachers for primary and second level schools as well as promoting scientific 'vocations' among high school students.

One special project in this area that deserves particular mention is the multicultural project "Astronomy for Development" aimed at schools with a considerable presence of immigrant pupils.

Father Louis CARUANA, S.J.

Apart from my normal lecturing and administrative duties at the Faculty of Philosophy of the Gregorian University, I remained engaged in research in the area of the philosophy of science and nature, mainly with two projects, one concerning artificial intelligence and the other concerning our responsibility toward living creatures.

Computers and sophisticated robots have become so powerful that some legal experts are now considering attributing legal personhood to them. In fact, in February 2017, the European Parliament passed a Resolution to attribute legal personhood to intelligent robots. If this is accepted as law, it will have very serious consequences for our self-understanding and for the way we live together as a community. In my current work in this area, I am focusing not only on legal and ethical issues but also on how the

meaning of key words is changing, for better or for worse, as these words are shifted from one context to another.

I presented some of this research in a paper entitled "Minds, machines and persons" during an international congress on the Philosophy of Mind held between 25 and 27 March at the Diocesan Seminary of the city of Morelia, Mexico. I presented other aspects of this research during an international congress on Transhumanism held between May 29 and 31 at the Pontifical University of Comillas, Madrid, Spain.

While in Mexico, I had the pleasure of visiting the Pontifical University at Mexico City, where I was given the opportunity on March 29 to address the university community on some topic of current relevance. In my lecture, I explored typical scientific and religious ways of thinking, highlighting their similarities and differences.

The second area of research that took much of my time during 2019 concerned our responsibility towards animals. Many people assume that serious reflection on animal science and animal ethics is a relatively new phenomenon to which traditional religions have little or nothing to offer. Nevertheless, as regards how we relate to nature in general and to animals in particular, religious traditions have played, and are still playing, a central role in molding the subliminal conscience of billions of people. In my research, I am exploring the extent to which the doctrine of the major religions converges on some useful central principles regarding animal care.

On August 27, I presented some of this research as a keynote speaker during the annual meeting of the European Association of Animal Science held in Ghent, Belgium. Toward the end of June, I was glad to see the completion of a four-year research project on biological evolution and the philosophical and theological problem of evil. The main researcher, Luca Di Gioia, a doctoral student working under my supervision, successfully defended his thesis on June 27. During the month of July, I spent some weeks of research at Campion Hall, Oxford, where, among other things, I met the director of the newly established Laudato Si' Research Institute, Professor Celia Deane-Drummond, and confirmed my availability as a member of its External Advisory Board for the coming three years.

Ileana CHINNICI

This year's major effort for me was finalizing the publication of the Angelo Secchi biography (see publications chapter). It has been a complex and exhausting experience, but I am grateful to have had the opportunity to draw the international community's attention to this very special Jesuit scientist. At the same time, I have started editing (together with CONSOLMAGNO) another book on Secchi. This book will collect contributions from experts across the many scientific disciplines that Secchi immersed himself in. In fact, my work on Secchi never ends, as the virtual exhibition dedicated to him which we organized for his bicentenary will also became a published volume.

In February this year, I received unexpected news: I have been invited to became a member of the Women's Consultation Group of the Pontifical Council for Culture. I accepted the nomination with pleasure and curiosity, happy to contribute to bringing the voice of women inside the organs of the Church: I am the only scientist among the group, and the only member living in Southern Italy.

In November, I made a short visit to a missionary community in Kinshasa (RDCongo). This was my third visit to this community and I am very happy to have had the opportunity to be with them once more, and support their activities, in favor of disadvantaged people of the area.

Michelle FRANCL-DONNAY

It's the 150th anniversary of Dmitri Mendeleev's publication of his periodic table of the chemical elements, and chemists all over the world, including me, have been celebrating this iconic image. I wrote three essays for Nature Chemistry on aspects of the periodic table, including one on heavy water, which drew on material from VOSS 2016 (on water in the solar system). I also wrote about the ephemeral

elements, discoveries that were thought to be new elements but turned out not to be. I was interviewed by the BBC about this essay, where I sang a snippet version of Tom Lehrer's The Elements featuring elements that never were. I was a consultant for a video produced by the American Chemical Society and PBS on women on the periodic table that appeared in late March. As part of the international celebration of the periodic table, a conference was held in late July in St. Petersburg, Russia (where Mendeleev had worked) at which I gave an address and joined the rest of the speakers in a toast to the table in Mendeleev's garden.

I continue to explore the sociology and philosophy of chemistry, publishing two articles, one considering the dueling definitions of chirality deployed by chemists and another, which referenced my experiences as a visitor at the Specola, on how the tradition of residential scientific institutes has left its trace on the modern practice of science. Two of my research students presented on our molecular topology work at the National Meeting of the American Chemical Society in the spring, on the structures of nanoputians (small molecules that resemble stick figures) and on ferrocene based oligomers with Möbius topology.

I contributed to a book of reflections for the Easter season, published by Liturgical Press and recently completed a manuscript for a book of Lenten reflections that will appear in both English and Spanish in early 2020. I occasionally blog at the VOF's Sacred Space, and continue to write for Give Us This Day and give days of reflection for local groups.

I enjoyed a visit with my colleagues at the Specola in July, a chance to tell the tale of the radioactive cat at the Vatican Observatory Foundation Annual Seminar in June, and a trip to Scotland with my husband to experience the Edinburgh Fringe Festival in which my oldest son was managing a play. Sadly, my father died at the turn of the year, he is missed by his six children and ten grandchildren. I was honored this fall with the American Chemical Society's Philadelphia Section award for my work in computational chemistry.

Father José FUNES, S.J.

My 2019 continued with research, leading project OTHER (Otros mundos, Tierra, Humanidad y Espacio Remoto which stands for Other worlds, Earth, Humanity and Remote Space) which is a laboratory of ideas that provides a multidisciplinary approach to the search for extraterrestrial intelligence.

The Search for Extraterrestrial Intelligence (SETI) research assumes that we live in an intelligence-friendly universe. But do we live in a spiritual-friendly universe? We include the spiritual quest in a new multidisciplinary approach to SETI. In a thought experiment, we consider two types of alien civilizations by including a Spiritual factor in the Drake Equation. Using the analogy of planetary biomarkers and the concept of noosphere introduced by Teilhard de Chardin, we propose two spiritual markers that could evidence the presence of a noosphere in an exoplanet.

FUNES lecturing at the Planetarium Plaza Cielo Tierra.

Father Matteo GALAVERNI

This year I had the opportunity to discover some new and interesting aspects of the Vatican Observatory.

I visited Tucson for the first time in January. It was very interesting experience to explore some of the many astronomical facilities (first of all the VATT!) and, in particular, to attend the "2019 Faith and Astronomy Workshop" (January 14-18). I really appreciated the presentations, the dialogue between the attendees, the visits and the stargazing nights. I really think it would be beneficial to organize a similar program in Europe.

Back in Italy I gave a course on science and cosmology for the Bachelor of Theology at the Reggio Emilia seminary (Studio Teologico Interdiocesano). We discussed the influences of the main cosmological models on philosophy and theology. We concluded our lessons with a visit to the Vatican Observatory headquarters in Castel Gandolfo and a seminar by MUELLER on Science and Faith.

At the end of the summer I attended two very interesting meetings for the first time: The meeting of Specola staff at the end of August and the Super-VOSS (Vatican Observatory Summer Schools) meeting in early September. The former gave me the possibility get to know the field of research of the Staff members better and to share some ideas on faith and science. The latter, on the other hand, gave me a unique opportunity to meet several of the alumni of the past VOSS and update eachother on our research projects and "extra-astronomical" life.

My scientific activity mainly focused on theoretical cosmology. I continued my research on cosmic birefringence (limits on rotation of Cosmic Microwave Background linear polarization) in collaboration with Fabio Finelli (INAF- Bologna). Moreover, with Gabriele GIONTI and Alfio Bonanno we worked on phenomenological implications of "new physics" (photon chiral anomaly).

It is not easy to coordinate scientific work, public outreach and pastoral service in Reggio Emilia - Guastalla diocese at the same time, but I hope to find a more stable balance in the coming years.

Theology students from Reggio Emilia visit the telescopes ontop of the papal palace at Castel Gandolfo.

Christopher M. GRANEY

Imagine that you are looking up at the late evening sky. Lined up across that sky are the first quarter moon, Saturn, Jupiter, and the star Antares. Now consider: were you to rank these in order of how large they seem to you, how would you rank them? Does Saturn appear larger or smaller than Antares? How many Jupiters could be lined up along the straight edge of that quarter moon? How does Jupiter compare to Saturn? And will your answers to these questions change if you observe these objects, not with your eye, but with a very small telescope?

These are the sorts of questions I pursued in my research this year. Why? Because these are the sorts of questions that astronomers asked themselves as they debated whether the Earth moves around the sun. Their answers to these questions influenced their views, not only regarding Earth's motion, but also regarding the nature of the stars and the structure of the universe.

For more than a decade my research has revolved about things like the optics of very small telescopes (such as were used in the seventeenth century), the writings of early telescopic astronomers (many of whom were members of a religious order called the Society of Jesus), and Latin—lots and lots of Latin (it was once the international language of astronomers).

I work in public astronomy outreach and teach college Astronomy 101, and these activities help me in my research. The astronomers who used the first generation of telescopes were smart people who were only beginning to learn about modern astronomy. Being exposed to smart people today who are beginning to learn about modern astronomy—the kind of people who attend public viewings at observatories or take an Astronomy 101 course to fulfill a general science requirement—helps me to understand those astronomers.

That extra help may be one reason this research has been very fruitful over the past decade, yielding many publications. It continued to be fruitful in 2019. My primary research interest in 2019 has been Johannes Kepler.

Kepler was a smart person—one of the more influential astronomers in history. His writings show that his ideas about the nature of the starry universe were very logical, very much based on observations—and very different from modern ideas. How could Kepler arrive at such non-modern ideas, while being so logical and observation-based? Because, he did not have a correct understanding of optics, of the wave nature of light, and of the relative apparent sizes of things like the moon and Antares. Indeed, no one in the seventeenth century did.

Kepler's views and those of other seventeenth-century astronomers suggest that our modern view of the universe, where stars are other suns, did not become scientifically viable until much later than is generally understood. This is the interesting conclusion toward which my research has been driving me in 2019. I am pleased have been able to do this work in 2019 as a new member of the Specola, and I look forward to probing these questions further in 2020.

Father Michael HELLER

Public lectures are an important ingredient of my activities. Some of them attract great audiences. My public lecture delivered in the Rzeszów Concert Hall was exceptional in this respect. Organized by the University of Information Technology and Management in Rzeszów, my talk was accompanied by Vivaldi's "Four Seasons", performed by Maestro Konstanty Andrzej Kulka (violin) with the Arso Ensemble. "Four Seasons": spring, summer, autumn, and winter, were combined with four scientific presentations – an unusual journey through the meanders of space, time and physics.

Dante MINNITI

I have spent 2019 mostly working on the ESO public survey VVVX (VISTA Variables in the Via Lactea Extended Survey). Among the many interesting new scientific results from this year, we have discovered planetary nebulae in globular clusters, published a near-IR extinction map of the Galactic plane, discovered five extrasolar planets, mapped the spatial distribution of microlensing events toward the Galactic centre, found a giant globular cluster behind the bulge, discovered dozens of type II Cepheids in the Milky Way, found a galaxy cluster hidden behind the Galactic plane, and studied the late evolution of a rare stellar merger.

One of the highlights of this year was the Nobel Prize in Physics 2019, that was awarded to Jim Peebles for his contribution to Cosmology, and to Michael Mayor and Didier Queloz (Lecturer of the VOSS 2007), for their discovery of the first extrasolar planet.

Also this year I was appointed Associate Editor for the international journal Astronomy & Astrophysics, hosting the first A&A office in Latin America.

As a global project in celebration of 100 years of the IAU, there is the IAU initiative to name extrasolar planets (*http://www.nameexoworlds.iau.org*), where all countries are given the opportunity to name an extrasolar planet and its hosting star. This included the following two planets that I discovered together with my collaborators: HD48265-b (for Argentina), and HD164604-b (for Chile).

The main lecturers for the VOSS 2007 were (from left to right in the attached picture): D. Queloz (Geneva Observatory, Switzerland), D. MINNITI (Chair, Universidad Andres Bello, Chile), F. Allard (Universite de Lyon, France), and F. Comeron (European Southern Observatory, Germany).

Father Giuseppe TANZELLA-NITTI

No doubt that the 50th anniversary of man's landing on the Moon was one of the most important events we celebrated during the year 2019. Many researchers of the Vatican Observatory were asked to give talks, answer interviews, offer comments. As a theologian involved in the science and theology dialogue, and an adjunct scholar of the Vatican Observatory, I was asked to comment on this anniversary in a number of events.

Then I decided to frame this anniversary within the broader view of the role of the human being in the cosmos, explaining to the public that scientific progress is part of the task the Creator entrusted to us on the earth. When exploring the cosmos and travel towards other celestial bodies, man bears witness to his Creator, being created in the image and likeness of God. The Vatican II Council's constitution Gaudium et spes pointed out, in this respect: "When man develops the earth by the work of his hands or with the aid of technology, in order that it might bear fruit and become a dwelling worthy of the whole human family, he carries out the design of God manifested at the beginning of time, that he should subdue the earth, perfect creation and develop himself" (n. 57). This is precisely what I commented on when I was invited to take part in a TV program, on July 20, broadcasted from the Astronomical Observatory of Monte Mario in Rome, in dialogue with Prof. Nichi D'Amico, President of the Italian National Institute for Astrophysics (INAF). Taking the cue from this 50th anniversary, I also organized a workshop in Rome, gathering about 40 young researchers to discuss the relationship between scientific progress and human progress. Franco Malerba, the first Italian astronaut who took part in a 1992 Atlantis Shuttle Mission, attended the meeting.

On March 7, the official presentation of my book *Religion and Revelation* took place in Rome. The book, published in Italian, is the third volume of a broader 4-volume treatise entitled *Fundamental Theology in Scientific Context*. This work is a significant outcome of my interdisciplinary research carried out as Adjunct scholar of the Vatican Observatory. Thanks to the generous funding of the Vatican Observatory Foundation, a shorter version of the whole treatise has been prepared for the English speaking audience and submitted to Claremont Press. It will be hopefully published in 2020 with the title *Perspectives on Fundamental Theology. Understanding Christian Faith in the Age of Scientific Reason*.

Among the various talks and lectures I gave during 2019, let me recall here the public lecture Knowing by elements: searching for a philosophical foundation (Dall'elemento al Fondamento) I gave at the "Genova Festival of Science" on November 2, on occasion of the International Year of the Periodic Table of Elements (150° anniversary from its discovery in 1869). The Festival is the most important Italian event dedicated to popularize science. More than 500 people attended the lecture.

On June 20, I took part in a Round Table organized at the headquarters of the Italian National Institute for Astrophysics (INAF), Monte Mario, Rome, addressed to scientists and philosophers, entitled Knowing the world, knowing oneself.

Among other events and talks, there are: a seminar I gave on February 14 at the Astronomical Observatory of Monte Porzio Catone, Rome, on the life and works of the Jesuit astronomer Angelo Secchi; a lecture on John Henry Newman's Idea of a University, on September 28, Rome, on occasion of his canonization held on October 13; the International Conference Thomas Aquinas on Creation and Nature I attended at the Angelicum Pontifical University on October 3-5. Two talks for High School teachers, entitled respectively "Scientific Thought and Christian Faith in the High School: guide-lines and challenges", and "The origin of the human being between biological evolution and theology of creation", were addressed to more than 200 people in Albenga (Savona), on February 23.

Presently, I am working at the organization of an International Conference on Theology and Science to be held in Trieste, on July 2020, within the European Science Open Forum (ESOF) 2020.

Chapter FOUR

Instrumentation and Technical Services

Keeping the 'machines' that allow us to do our work well-oiled is a collaborative effort and we are grateful for the professionalism of the team that works with us to do so. This year there have been a series of changes and upgrades at the Vatican Advanced Technology Telescope in Tucson and at the Specola, helping to bring both virtually closer together.

Personnel

On June 26, Alyson Ford took up additional duties as Assistant Director, Steward Observatory, while retaining her role as the Manager of the Radio Telescopes (ARO) of Steward Observatory and her position as an Assistant Astronomer with Steward Observatory. As Assistant Director, she became responsible for both ARO and Mountain Operations. On the same day, Paul S. Smith became Manager of Mountain Operations. Taras Golota's last day with Steward was July 26. His position of VATT's Manager and Principal Engineer (Electrical) ceased in the context of these changes.

Kelly Waldvogel, mechanical engineering undergraduate student from Cornell University, worked with Michael FRANZ July 1 to August 9.

After being custodian of the telescopes (palace and garden domes) at the Roman branch of the Specola for 11 years, BROWN passed the job on to D'SOUZA, who now will oversee them.

VATT Upgrades

Several upgrade projects continued: network, commissioning of the Mount Control Unit and TCS-NG, the primary mirror position monitoring system, and the automated collimation and collimation maintenance procedure. GRAY supervised the replacement of the SW-facing French window (sliding door) and two ordinary E-facing windows on the ground level.

The major project of 2019 turned out to be the "guider box". The goal was to replace the old motors with new ones. While the former were run from driver electronics in the VATTtel room, the latter are Moog Inc. SM2316 Class 5 D-Style smart motors commanded via Ethernet.

The mechanical aspects of the project were supervised by Michael Franz, the software aspects by Scott Swindell. Other contributors were Christopher Johnson, Jeff Rill, Paul Arbo, and Dan Avner. The center mirror (both sides) and the U-mirror (one side) were realuminized by Composite Mirror Applications Inc.

Melanie Waidanz cleaned the following 18 VATT filters: U, B, V, R, I; SDSS u', g', r', i', z'; Viner V+R, Schott GG475, S8612, GG400, GG495, OG450, ND-1.0 and 2.0. (A filter marked ZULO350 was not cleaned due to a lack of information.)

Meteorite Acquisitions

This year, we had a small budget for purchases, which were used to acquire an 8-gram specimen of the CM carbonaceous chondrite Murchison, and a 33-gram specimen of the CV carbonaceous chondrite Allende. These will be used for a study of the heat capacities of carbonaceous chondrites at low temperatures. In addition, the dealer Dustin Dickens (Top Meteorite) donated three specimens of the CK carbonaceous chondrite NWA 12925 (158 grams total, two of the appropriate size for the aforementioned heat capacity study and one suitable for display) and an unnamed Eucrite. The continued growth of the Vatican meteorite collection is largely dependent on the generosity of benefactors.

Meteorites acquired this year for the Vatican meteorite collection.

Operation of the Carte du Ciel telescope

During most of 2019 Claudio Costa continued assisting and coordinating the operation of the restored historical Carte du Ciel telescope. Many new accessories have been put in place which render the telescope more user friendly.

For example, a new optical focus extractor for the photographic telescope is being implemented. A prototype has been designed and tested to demonstrate that the photographic focus can also be easily extracted and used to produce images with modern electronic sensors (CCDs and CMOSs). Due to the original (1891) design of the chromatic correction of the objective which was designed to produce sharp images in the blue region of the spectrum, provisions have been taken to allow the interposition of colored filters to allow composition of color images in spite of the need to adjust the focal length by the focuser. The new focus extractor, currently under final manufacturing, uses high quality apochromatic optics and has no significant back focus.

The small telescope used to image the graduated scale of the declination circle (actually of the Zenithal distance) has been cleaned and remounted and a new illumination, with LEDs of the circle is being implemented. Added to this, the focal end of the collimator has been reinforced and installed to safely hold the weight of the new focus extractor and eyepieces and a new green light laser pointer has been mounted on the tube to greatly simplify pointing to the celestial objects. Moreover, an electrical heater is provided to prevent the laser beam to became too faint in cold weather, but it will require a power supply which will replace the batteries now in use.

In view of all of these improvements, Claudio has led a series of training sessions with a small group of telescope operators including most of the Vatican Observatory Astronomers and staff on the correct usage of the telescope during public visits, rendering it truly operational.

Moreover, Claudio cooperated in moving the Coronado H-Alpha solar telescope from the Visuale dome in the Palace to the Carte du Ciel dome. A new portable equatorial mount has been acquired and installed in the dome to hold the Coronado to allow group of daylight visitors to observe images of the solar chromosphere from the terrace outside the dome.

During the year Claudio also conducted more than twenty observing sessions with the Carte du Ciel telescope demonstrating the usage of the historical telescope and of the modern Celestron 8 telescope to several private visitors of the Specola and many amateur astronomers' groups.

Digitalization of the Specola Archives

The digitization of the Vatican Observatory archives continues with the double astrograph plates. The next step will be to make the digitized material accessible to the international scientific community and will mean collaborating with an international institution with experience in creating web archives. In the meantime, we have equipped ourselves with a new Epson Expression 12000 scanner to complete the digitization work.

Multimedia and communications

The ability to stay connected and communicate virtually through the Internet has huge benefits for the field of scientific research. It also shortens the distance between Rome and Tucson and, indeed, anywhere else in the world. In an outreach context, teaching through the web - or webinars - are becoming very popular. So in 2019 we decided to equip a small multipurpose studio for videoconferencing and for recording short videos. The purchased equipment includes: studio lights, green screen, desktop computer for editing, a second camera lens, additional microphones and other accessories. When complete, the studio will allow our members to participate in high quality videoconferencing as well as record and edit short promotional and instructive video materials.

PPU Restoration and Maintenance 2019

Thomas Rebenyi, master clocksmith at the Munich Deutsches Museum, spent a week at the Observatory in August. In addition to carrying out regular maintenance work on seven previously restored clocks, he also did special restoration work on the clock which regulates the motion of the Double Astrograph, a 1935 telescope located under a dome atop the Apostolic Palace. This precision pendulum clock is quite rare. Research done by Thomas Rebenyi and specialist Jürgen Ermert indicates that it is Riefler clock #103, an entry for which can be found in the catalog of the clocks produced by Riefler.

Last year, the PPU, Dent No. 1346 was mounted in the dome of the Carte du Ciel with a gravity escapement. This year, the alignment of the gears needed correction and regulation. According to the documents of Mr. Dieter Riefler, this clock and the Riefler Invar Pendulum Type K, No. 831, were delivered in 1908: the entry in the firm's book reads "Lenz Werk Vatic. Specula Rom 17.3.1908".

In addition, the Specola possesses a special PPU-Mother clock (Riefler No. 539) which has a special three-circle dial; research has indicated that it is one of only five such pieces ever built. For this clock, the gravity-enabled levers were cleaned, reset and oiled to prevent further corrosion. Because some of the outer jewel bearings are broken, they need to be replaced for the clock to function reliably.

Thomas Rebenyi, master clocksmith at the Munich Deutsches Museum.

Chapter FIVE

Education and Outreach

Through their interdisciplinary efforts, Vatican Observatory staff and scholars make a vital contribution to bridging faith and science and popularizing astronomical research in the age of technology. In 2019 we took time from 'doing the science' to offer hundreds of academic lectures and conference presentations, online 'webinars', formation workshops and even spiritual retreats to show people the way to God through the starlit skies.

SuperVOSS

It was a memorable moment during the fourth SuperVOSS. Dante MINNITI had just relayed a worldwide announcement. Immediately, loud cheers and congratulatory applause broke out among the participants. An appreciative Heino Falcke acknowledged the reaction and gave appropriate thanks on behalf of his large team.

This announcement on September 5 was, of course, that the Event Horizon Telescope (EHT) team had won the $3 million Breakthrough Prize for their epic imagery of the supermassive black hole at the center of the M87 galaxy. Earlier, just before lunch on this third day of the meeting, Falcke had reviewed the latest results of the EHT and plans for its future expansion, including those involving space-based interferometry. Meanwhile, he could claim that general relativity works in its prediction of black holes, while it may not be the only working theory.

A SuperVOSS is the gathering of alumni (and families) from Vatican Observatory Summer Schools for a few days of reconnection with their fellow students and teachers, for making new connections with those from other schools, and for sharing and probing advances in astrophysics.

While the EHT announcement was special, the enthusiasm with which it was received by everyone was typical of the spirit among alumni as they listened to each other's talks.

The program title of the SuperVOSS was The Search for Extra Astronomical Life. Now read that again carefully. It doesn't directly involve aliens. The title acknowledges that some alumni have branched out into fields other than strictly academia. Indeed, one has become a NASA astronaut. So talks on outreach in astronomy and beyond featured significantly, and they were fascinating examples of the ingenuity of alumni applied to education, media, and service.

Heino Falcke at SuperVOSS 2019

In addition, we heard about many aspects of planetary, stellar, galactic, and extragalactic astrophysics, and the overarching cosmology. As promised, it was an exciting four and a half days meeting.

With the 16 Summer Schools since their start in 1986 to draw from, the composition of this SuperVOSS had a large range in age and, as usual, countries. We met everyone from graduate students to emeritus professors. It was held at Centro Mariapoli Internazionale, a conference center in Castel Gandolfo, and so it was close to the Vatican Observatory headquarters. Some participants were lodged at Centro Mariapoli, while others stayed at a nearby hotel. It all seemed to work well. The space of the Centro Mariapoli was abundant, while its gardens proved a delightful setting for the conference dinner one warm evening.

On one afternoon there was the statutory visit to the gardens of the Papal Villas and to the headquarters of the Vatican Observatory. Now, the majority of the schools had taken place before the move of our headquarters in 2009 to its new site. It was a pleasure to demonstrate how appropriate this had become for our work and community residence. There was also a chance to show off the newly restored Carte du Ciel and Schmidt telescope domes, now turned into a very fitting facility for presenting the observatory's history and current research, along with nighttime views of the heavens. Viewing through the 19th century Carte du Ciel gives one a real connection with the observatory's history.

Thanks are sincerely due to the six-strong Scientific Organizing Committee and to its indefatigable support staff (Federico Balzoni and Antonio Coretti). They will all be gratified that this SuperVOSS, as its three predecessors, very much fulfilled its aim of communicating new discoveries, of promoting them in fellowship, and of telling the world about what we love both in science and beyond.

Education and Public Outreach

As part of their education efforts this year, BOYLE with JANUSZ presented a description of the Vatican Observatory to a select group of high school students at Kaunas Jesuit Gymnasium, Lithuania in July.

BROWN gave lectures and popular talks at various educational events and institutes throughout the year. During his time at St. Louis University (SLU), Missouri, USA, his outreach included presentations on "Faith and Science in the Catholic Tradition" to the Campion Society at the Catholic Studies Centre and to the Theology 1000 class * on "The Jesuits and the Vatican Observatory" given to U101 class * on "The Catholic Church and the Vatican: A Long Tradition of Astronomy" at the First Friday Speaker lunch. He also spoke on "The Church, the Jesuits, and the Sciences" at the Ignatian Speaker Lunch for Faculty and Staff and on the same subject to the Cannonball Club, SLU High * he gave a lecture to SLU High astrophysics class, on "Astrophysics and the Vatican Observatory".
He also gave a university lecture at the Catholic Newman Center of Washington University, again in St. Louis, MO, on "Stellar Evolution, Galaxies, Meteorites, and Other Findings of the Vatican Observatory" and in July he gave a lecture on "Pepsi and Host Stars" at the Vatican Observatory Foundation 2019 Annual Seminar at Georgetown University, Washington D.C., USA. BROWN was also main celebrant and homilist at the Gold Mass (for scientists) at Kendrick-Glennon Seminary, St. Louis, MO, USA.

CONSOLMAGNO continued his teaching of an online high school class in astronomy via the Jesuit Virtual Learning Academy. In addition, he made a number of online presentations, including: Youth Ministry, Our Lady's Immaculate Heart Church, Ankeny, Iowa, USA * Marcon Science Fiction Convention * Michigan Lowbrow Astronomers * Mayfield Senior School of the Holy Child Jesus, Pasadena, CA * Georgetown College (Kentucky) USA. Staying in the United States, he also made many presentations in person, including: "Faith and Astronomy Workshop," Tucson, AZ * "Astronomy, God, and the Search for Elegance," Oral Roberts University, Tulsa, OK* "From Galileo to Laudato Si'", University of Arizona * "Adventures of a Vatican Astronomer," University of Pennsylvania * "Adventures of a Vatican Astronomer," St. Paul Choir School, Cambridge, MA * "Galileo Affair in Context", Harvard University * five panels, Boskone Science Fiction Convention, Boston, MA * "Jesuits and Science", St Thomas More Parish, Glendale, AZ * "God's Mechanics", University of Kentucky; * "A Life Among the Planets," University of Dayton * "Why Do We Look Up?", Immaculate Conception Parish, Botkins OH * three presentations to Sacred Heart Seminarians at Redemptorist Renewal Center, Tucson * "Adventures of a Vatican Astronomer," Yale Club, Tucson, AZ * "Finding God in the Universe," Stanford University * "Scientific Inquiry and the Catholic Tradition", Fordham University, New York * five panels at the Convergence Science Fiction Convention, Minneapolis, MN * "SciFoo", Mountain View, CA.
During the course of the year CONSOLMAGNO's outreach included talks on "Cosa possono dirci le Sacre Scritture sulla cosmologia moderna?", Sarno, Italy * "Fantascienza e Teologia", Istituto Superiore Scienze Religiose, Vincenza, Italy * "Our God is Too Small", Otago University, Dunedin, New Zealand * "Life as a Scientist and Jesuit", Christchurch, New Zealand * "Our God is Too Small", New Zealand Christians in Science, Aukland NZ * "Discarded Worlds," WETA Chalk Talk, Wellington, New Zealand * "Our God Is Too Small", Wellington Astronomical Society * "Discarded Images", Cork Astronomical Society, Ireland * six presentations at Worldcon 76, Dublin, Ireland * "Is Your God Too Small?", Lay Centre Rome, Italy * "Adventures of a Vatican Astronomer" at Glasgow University and "Why Do We Look Up?", Royal Philosophical Society of Scotland * "God and the Stars," St. Bride's Hall, Motherwell, and "Strange Cosmologies," Scottish Institute of Physics * "Science and Faith", Groave Academy and "The History of Strange Ideas," Museum of Science, Dundee * "Is There Purpose in the Cosmos?", Grasping the Nettle annual meeting, Edinburgh * "Philosophy of Meteorites," Institut de physique du globe de Paris, France * "Discarded Worlds", Christmas Lecture, Bucharest, Romania. In May, CONSOLMAGNO led retreats on the theme "Science and Creation" in Templestowe, Victoria, Australia and in Los Altos, CA, USA.

CORBALLY used Father Angelo Secchi's life to illustrate "How Faith and Science Mix" before various audiences, including: the Faith and Astronomy Workshop in Tucson * the Lowell42 program's public lecture at the Lowell Observatory, Flagstaff, AZ * a Kino Heritage Society Seminar during the Sacred Heart Seminary of Wisconsin's visit to the Vatican Observatory, Tucson, AZ * a Tucson visit by senior students from Loyola High School of Los Angeles, led by their honors astronomy teacher, Andrey

Aristov * at the Biggar Science Festival, Scotland, with a talk entitled "A Revolution in Astronomy," recognizing Secchi's place in the sesquicentennial of the Periodic Table * talked to members of the Mountain Shadows Presbyterian Church, Catalina, AZ, on "When I survey your heavens….", and helped them reflect on their field trip to Kitt Peak National Observatory a week earlier * to students at Farleigh School, Andover, England, and to the residents and community of St. Joseph's Care Home, Glasgow, Scotland, on "Bridging Faith and Science at the Vatican Observatory." In October, CORBALLY and Margaret Boone Rappaport gave a lecture on the "Emergence of Religion in Human Evolution: Lessons from Neuroscience; Lessons from the Hearth". The event was presented by the Chestnut Hill College's Institute for Religion and Science, and hosted by Prof. Kathy Duffy, SSJ.

D'SOUZA gave seminars at the following universities and institutes: University of California, Riverside, CA * University of California, Irvine, CA * University of California, UCLA, CA * Carnegie Institute of Science, Pasadena, CA * University of Minnesota, Minneapolis, WI * University of Michigan, Flint, MI, USA * Macalester College, St. Paul's, WI, all in the USA * Western University, Ontario, Canada * Observatorio Astronomico di Roma, Monte Porzio, Rome, Italy * Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan * National Tsing Hua University, Hsinchu, Taiwan. D'SOUZA also gave a series of talks on science and religion, including: on "Astronomy and the Quest for the Transcendental" at the University of Michigan Medical School Program on Health, Spirituality and Religion * on "Finding New Narratives for Science-Religion Dialogue" at St. John's University, Collegiville, MN * "Faith & Science: What the Galaxies tell us about God", Faith & Life Series, at St Philip the Deacon, Lutheran Church, Plymouth, MI * on Medicine, Religion and Vaccine Hesitancy, 8th Annual William Davidson Medical Education Week at the School of Medicine, Oakland University William Beaumont Hospital, Detroit all in the USA. In Taiwan hepresented a paper on "Divine Action Amidst a New Emerging Narrative of Science" at the Center for the Study of Science and Religion, Fu Jen Catholic University, Hsinchuang, Taipei.

GABOR helped at a star party in Safford (or rather Moon gazing party) * took part in a rocket launch party in Safford * organized Holy Family Parish's Star party in Tucson * gave a talk in Green Valley at Sonora Astronomical Society * at the Redemptorist Renewal Center in Tucson to the participants of the sabbatical program * at the Mount Graham International Observatory Docent Appreciation Dinner in Safford * gave several talks in the Czech Republic in Valtice, Znojmo, Trebic, Zdar nad Sazavou and Letovice.

GIONTI gave a series of educational lectures and popular talks throughout the year including: "Wilson-like lattice gravity in the Palatini Formalism and the Problem of Quantum Measure in Regge Calculus" at the FLAG meeting, Theoretical Physics Department of the University of Bologna, Italy * to the group of Prof. Martin Reuter at the Theoretical Physics Department of the University of Mainz, Germany * on "Some Aspects of the Hamiltonian Analysis of Asymptotic Safety Quantum Gravity" at KIAS in Seoul and at the Physics Department of Sogang (Jesuit) University is Seoul, South Korea * gave two popular lectures to undergraduate students of the LUMSA University in Rome, Italy * gave a talk on "El Comienzo Del Universo Y La Cuestión De Dios: Un debate entre ciencia y fe" at the Universidad de La Mistica, Avila, Spain * "L'inizio dell'Universo, la questione della vita e di Dio" at the Aeronautical Engineering department at University II "Luigi Vanvitelli" of Naples, Aversa, Italy * participated in the panel discussion "L'uomo di fronte all'Universo in espansione: dalla legge di Hubble-Lemaître all'energia oscura" at the cultural center "EURESIS" in Milan, Italy * delivered a talk on "Some features of the Hamiltonian Analysis of Asymptotic Safe Quantum Gravity" at 3th FLAG meeting in Catania, Italy * at 22nd International Conference on General Relativity and Gravitation in Valencia, Spain * delivered a talk on "Some aspects of improved gravitational action through Brans-Dicke theory" at the Conference "Quantum Gravity and Matter" IWH, Heidelberg, Germany.

MACKE gave a popular talk on "Meteoriti ed Altro Materiale Extraterrestre" to the Associazione Arma Aeronautica, Caserta, Italy, and on Astronomy concepts and a night of stargazing, as part of a summer camp program at Santuario del Monte Lussari, Monte Lussari, Italy.

MUELLER gave the following presentations: on "The History and Activity of the Vatican Observatory" to the Vatican Observatory Foundation Seminar, Georgetown University, Washington DC and to the Friends of the Vatican Observatory, Belleair Beach Florida * on

"Christopher Clavius's Influence on Science-Math Education" to Westchester Amateur Astronomers MUELLER also dedicated much of his public outreach to offering spiritual retreats and workshops with a science/faith theme in Bellarmine Retreat House, Barrington IL * Cloisters on the Platte Retreat House, Omaha NE * Franciscan Renewal Center, Phoenix AZ.

OMIZZOLO together with the Camaldolese monk Ivan Nicoletto from Berkley, USA, led a two-day permanent formation workshop for men and women religious at the Camaldoli monastery (AR) on the composition of the Universe.

CHINNICI gave a public presentation on women in science "Donne e scienza: un binomio possibile?", S.Agata di Militello, Messina, Italy.

FRANCL – DONNAY gave public presentations on the following: "Working on God's Time" St. Mary of the Assumption * "Molecular Monsters" Mallory Lecture at Bryn Mawr College* "Amid the Burning Layers of Grace" Daylesford Abbey * "Isotopic Enrichment" Mendeleev 150 * "Molecules on the Edge" Philadelphia Section Award address.

FUNES taught a class on "The Philosophy of Nature" to grad students and a seminar on "Science and Religion" for students with a variety of majors at the Universidad Católica de Córdoba, Argentina * was invited to Santa Clara University to collaborate on a project that explores the role of science and religion as a platform for interreligious dialogue * as part of his activities as chair of Science, Religion, and Education that was created last year at Universidad Católica de Córdoba, FUNES organized the second workshop on "Science, Religion and Education" for high-school teachers focusing on the Galileo affair * held a panel with Dr. Aleksandar Zecevic, Santa Clara University, on "Science and Religion: From Silicon Valley to Córdoba" at the Universidad Católica de Córdoba * lectured at the National Academy of Sciences on Frontiers of Astrbiology at the Planetarium Plaza Cielo Tierra, Córdoba, Argentina * gave lectures at Colegio del Salvador in Buenos Aires and Instituto Escuelas Pías in Córdoba, Argentina.

HELLER continued to present public lectures in his native Poland exploring the themes of faith and science, including: "Contemplation of the Universe" * "How to justify the history of the Universe" * "Man and the Universe".

GALAVERNI gave a course on "Interactions between Cosmology, Philosophy and Theology" for the Bachelor of Theology at the Studio Teologico Interdiocesano in Reggio Emilia, Italy * a talk on "Faith and Science: a possible dialogue" at the Università Cattolica, Piacenza, Italy. MINNITI among his many other activities this year gave a few public presentations at Colegio San Jose de Calazans * Colegio San Francisco de Asis, and at Universidad Andres Bello, Santiago, Chile.

Presentations, Academic Activities and Conference Participation

BOYLE was first author on a poster paper at the 233rd Meeting of the American Astronomical Society, Seattle, Washington, in January * participated in the fourth Super-VOSS 2019 "The Search for Extra-Astronomical Life", Centro Mariapoli, Castel Gandolfo, Italy, in September * participated in the PEPSI - VATT project workshop led by Klaus Strassmeier and GABOR, Castel Gandolfo, Italy, in September.

BROWN attended the 234th Meeting of the American Astronomical Society, St. Louis, MO in June * "Stars and their variability, observed from space: Celebrating the 5th anniversary of BRITE-Constellation," held at the University of Vienna, in Vienna, Austria, in August * attended the 2019 meeting of staff of the Vatican Observatory, Castel Gandolfo, Italy, in August.

CONSOLMAGNO participated in the IAU 100th Anniversary meeting, Brussels, Belgium, April * European Planetary Science Conference/Division for Planetary Sciences joint meeting, Geneva, Switzerland, in September.

CORBALLY participated in the Annual Conference of the Institute on Religion in an Age of Science, on Star Island NH, June * participated in the fourth Super-VOSS 2019 "The Search for Extra-Astronomical Life", Centro Mariapoli, Castel Gandolfo, Italy, in September * with GABOR participated in the Annual General Meeting of the International Dark-Sky Association, held in Tucson, Arizona, in November.

D'SOUZA participated in the following scientific conferences: "Light in the Suburbs: Structure and Chemodynamics of Galaxy Halos" in Sexton, Italy * "Small Galaxies, Cosmic Questions" in Durham, UK *

participated in the fourth Super-VOSS 2019 "The Search for Extra-Astronomical Life", Centro Mariapoli, Castel Gandolfo, Italy, in September * "Extremely Big Eyes on the Early Universe" in Rome, Italy.

GABOR taught a tier II general education course on the history and philosophy astronomy, ASTR 320, in the Spring 2019 semester at the University of Arizona, AZ, USA * gave invited talks at the Conference on Faith and Science (COFAS) in Phoenix, AZ * at the Machina ex Machina workshop in Tucson, AZ * at the event commemorating 250th anniversary of Maximilian Hell's observations of the Transit of Venus of 1769 (he spoke by Skype on Hell's Jesuit teachers and colleagues), Stiavnicke Bane, Slovakia * at American Mensa's National Convention, Phoenix, AZ, USA * participated in the Inaugural General Assembly of the European Astrobiology Institute, Liblice, Czech Republic * at the Day in Honor of Jiri Veltrusky organized by the Prague Linguistic Circle and the Theatre Research Society * in the International Dark-Sky Association's Annual General Meeting and Conference.

GIONTI participated in the following international conferences: "IX CURSO Nueva Cosmología: conciencia de lo Sagrado en cada Realidad del Universo" Càtedra Josefa Segovia, Cites-Universidad de la Mistica, Avila Spain, in March * "Current Problems in Theoretical Physics" Aspects of Nonperturbative QFT, Foundations of Quantum Theory, Quantum Spacetime *XXV Edition*, in April * "Gravity and Other Fields under the Volcano", Catania, Italy, in June * 3rd FLAG meeting "the Quantum and Gravity" Catania, Italy, in June * "22nd International Conference on General Relativity and Gravitation, Valencia, Spain, July 7-12 * "Quantum Gravity and Matter" at IWH Heidelberg, Germany, in September * the 7th International Symposium of the Korean Society of Theology and Thought "*Creatio ex Nihilo*: New perspective from Physics, Theology and Philosophy", Seoul, South Korea.

KIKWAYA took part in the fourth Super-VOSS 2019 "The Search for Extra-Astronomical Life", Centro Mariapoli, Castel Gandolfo, Italy, in September and the EPSC-DPS 2019 in the Geneva Convention Center, Geneva, Switzerland.

MACKE attended the American Physical Society March Meeting in Boston, MA, USA and the 10th Meteoroids Meeting in Bratislava, Slovakia.

MUELLER taught a course titled "Philosophical Questions in Physics" at the Pontifical Gregorian University during the Spring semester * gave academic presentations to the Pontifical Institute Redemptor Hominis, "Reasons for Belief, from Astrophysics" * Jesuit Novitiate, USA Western Province, on "The Catholic Church and Science-Faith" and on "The Essential Role of Philosophy" * International Astronomical Union (IAU) Executive Committee Meeting, Accademia dei Lincei, on "The Vatican Observatory and the Early History of the IAU" * at Loyola University Chicago, on "Jesuit Education and Science-Faith."

ALTAMORE attended the conference "Historical meteorological observatories: from data rescue to climate change studies", MIBAC - Sala Spadolini, Rome, Italy * SETI Meeting 2019, Presidenza INAF Rome, Italy. CHINNICI was invited to the following seminars: "Angelo Secchi e la fondazione della Società degli Spettroscopisti Italiani", LXIII Congresso della SAIt, Rome, Italy * "Astronomia e visioni del mondo: L'Uomo e il Cosmo nella Storia - Paradigmi, miti, simboli," Palermo, Italy * "Precursors to IAU: Paris Observatory and the Carte du Ciel project", IAU Centenary Celebrations, Paris, France.

FRANCL-DONNAY attended the Mendeleev 150 Conference, St. Petersburg, Russia.

HELLER gave a lecture at the Congress of Polish Physicists on the theme "Is physics the science of matter?"

GALAVERNI participated in the Faith and Astronomy Workshop, Redemptorist Retreat Center, Tucson, Arizona, USA * Cosmology meeting "UniVersum 2019", Milan, Italy * Super-VOSS 2019 "The Search for Extra-Astronomical Life", Castel Gandolfo, Italy, in September.

GRANEY attended and presented at the 14th Biennial History of Astronomy Workshops at the University of Notre Dame (Indiana, USA), his presentations included "Huge, Unmoving, Dull: Kepler's View of the Stars, and his Criticism of Bruno" and "Sizes of Celestial Bodies: An Image from the Harmonia Macrocosmica of Andreas Cellarius" (part of a joint presentation with Pedro Raposo, Adler Planetarium).

MINNITI gave invited talks at the following conferences: Sexten Center for Astrophysics Workshop on "Galactic Archaeology in the Gaia Era", Sesto, Italy * First Max

Planck-La Serena (MPA-ULS) Workshop, La Serena, Chile * IAU Symposium 353 on "Galactic Dynamics in the Era of Large Surveys", Shanghai, China * 10th VVV Annual Science Team Workshop, Gemini Observatory, Hawaii, USA * participated in the fourth Super-VOSS 2019 "The Search for Extra-Astronomical Life", Centro Mariapoli, Castel Gandolfo, Italy, in September. In addition, MINNITI visited and gave invited talks at the FCFM at Universidad de Chile, Santiago, Chile and the NASA AMES Space Research Center California, USA.

News and Media Coverage

CONSOLMAGNO conducted interviews with several TV and radio programs, including: Tulsa, Oklahoma; TV 2000 "Soul", Rome; Radio New Zealand; TVNZ "Q+A" New Zealand national television program; Jennifer Fulwiler Show, Sirius XM Radio; EWTN Television; BBC Scotland, radio and television; Popular Science video; Radio Vaticana. He also conducted interviews with press and online media, including: *Catholic News Service*; Wapak (Ohio) Daily News; New Zealand *Catholic*; *The Press* (Christchurch, NZ); *Vox.com*; *Le Figaro*, Paris; *Unleash the Gospel* (Archdiocese of Detroit); *La Voce dei Berici* (diocesano di Vicenza); *Il Giornale di Vicenza*; British Columbia *Catholic; Aleteia*; NBC News Website; Katholicsche Nachtrichten; *Kooperation-Kirchenzeitungen* (der Diözesen Eisenstadt, Feldkirch, Innsbruck und Linz, Austria); *National Catholic Register*; America; SIR (Religious Information Service of the Italian Bishop's Conference); *Crux*; *Forbes.com*; *Desde la fe* (Arzobispado de México); The i (London, England); *Katholische Sonntagszeitung*; Vita (Diocesana Pinerolese); *The Courier* (Dundee, Scotland) Podcasts are an increasingly lively multimedia forum for outreach. CONSOLMAGNO was hosted on a series of podcasts, including: Space4U, Weekly Space Hangout, The Mac Observer "Background Mode", Homeschool Connections Online, The Creative Writer's Toolbelt, Looking Up, South Africa Astronomy.

CORBALLY was interviewed three times and answered phone-in questions on the Drew Mariani Show, Relevant Radio: about the SpaceX Starlink Low Earth Orbit Satellite Constellation, and UFO sightings by military pilots and radar; a missed, very close asteroid; and the Christmas Star (December 20). On December 4 in Tucson, CORBALLY gave a video interview to James Kelty for an Eternal Word Television Network EWTN documentary on Padre Eusebio Kino. The local videoing is being facilitated by the Kino Heritage Society, of which he has long been a member.

GABOR ended his radio blog on Radio Lumen, Slovakia, broadcasting the last, 211th blog on January 22. He collaborated with the Czech Television on a half-hour documentary which aired on October 20 under the title "Papal Astronomers" in the cycle Faith Journeys.

GIONTI took part in diverse programs for Italian national cable TV including RAI Educational's Nemex-Nautilus "Buchi neri, non più oscuri"; RAI UNO "A Sua immagine", "Tg Estate" on TV 2000, marking the 50th anniversary of the Moon landing.

KIKWAYA was interviewed by Radio Catholique Francaise, Liege, Belgium, as part of the program "L'homme sur la Lune"; by Radio Vatican monde on an espisode titled "L'homme sur la Lune, une lecon d'humilite"; again by Radio Vatican on this year's meeting with Pope Francis and for the online news portal *Aleteia* on faith and science *Dieu ne recule pas devant les avancees de la science*.

MACKE gave a series of interviews for TV, radio and print media covering areas from meteorites to the Apollo 11 mission. These include: for Rai Radiotelevisione Italiana – TG Scientifico Leonardo; the *Texas Catholic Herald; Catholic News Service* and *America Magazine*. MACKE is also an able blogger with his expertise feeding the *Sacred Space Astronomy* blog with the "Specola Guestbook" series and the "Religious Scientists" series. He also contributed to *The Catholic Astronomer* with a post on **"**Gems, Minerals… and Meteorites."

FRANCL – DONNAY was interviewed by Science in Action, BBC; NPR (KJZZ); *The Washington Post*.

FUNES was interviewed for the documentary "Al Ras Del Cielo. Miradas Al Sur" by Canal Encuentro; by the *Catholic News Service* and Radio Mitre of Argentina.

GRANEY is editor of Faith and Science, he writes a bi-monthly science column for The Record, the newspaper of the Archdiocese of Louisville, Kentucky and he also writes for *Sacred Space Astronomy*. During the past year he contributed to a series of stories regarding the 50th anniversary of Apollo 11, including: Laurel Deppen, "How a Louisville man eavesdropped on Neil Armstrong's historic Apollo 11 moon landing", Louisville Courier-Journal; Marnie McAllister, "Local men listened-in on lunar landing", *Archdiocese of Louisville Record*; Marnie

McAllister, "Through crackly transmission, these two eavesdropped on Apollo 11 landing", *Crux*.

Appointments to committees and boards:

In 2019, CONSOLMAGNO was invited to serve on the following boards and committees: The Science Advisory Board, SETI Institute; Adler Planetarium Sloan Project Advisory Board; Arecibo Observatory Science Management Advisory Council; IAU Working Group on Planetary System Nomenclature; chair, Mars Task Group.

CORBALLY joined, by invitation, the Executive Committee of the International Astronomical Union's Working Group on Astronomy for Equity and Inclusion. GIONTI joined, by invitation, the Organizing Committee of the "Science and Faith Satellite Conference" of the European Science Open Forum (ESOF 2020), to be held in Trieste in 2020.

CHINNICI served on the organizing committee and was co-chair of the SOC International workshop "Preventive conservation in museums, libraries and archives: scientific collections as a case study," Palermo, Italy.

FRANCL – DONNAY served on the board of the Institute for Religion and Science and the board of the Open Chemistry Collaborative in Diversity Equity (OXIDE).

Awards and distinctions

CONSOLMAGNO received the University of Dayton Marionist Award for science and faith and the Associazione Medici Cattolici Italiani 2019 *Fides et Scientia* Award.

At the annual Star Island Conference banquet on June 28, CORBALLY received the Institute on Religion in an Age of Science (IRAS) 2019 Academic Fellow Award "in recognition of his distinguished career of astronomical and interdisciplinary research." He is a long-time member and leader of IRAS, having served as IRAS President from 1999- 2002.

GIONTI was appointed associate fellow of the National Laboratories of Frascati (LNF) of the Italian Institute for Nuclear Physics (INFN) for the year 2019. He also became fellow of The International Society for General Relativity and Gravitation.

FRANCL – DONNAY received the American Chemical Society Philadelphia Section Award, 2019.

In recognition of a lifetime dedicated to building bridges between science and religion, HELLER was awarded a Doctorate honoris causa, by the Technical University of Rzeszów; a distinction from the Foundation for Polish Science and the *Totus tuus* award from the Work of the New Millennium Foundation.

This year MINNITI was appointed Associate Editor for the international journal *Astronomy &Astrophysics*, hosting the first *A&A* office in Latin America.

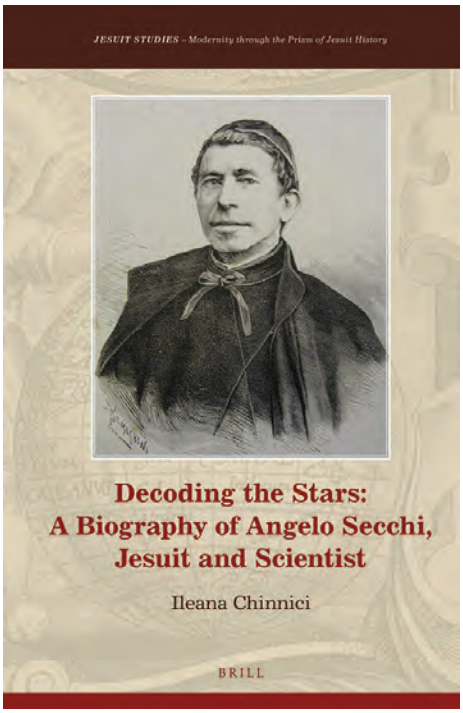
Chapter SIX

Publications

Through their academic publications Vatican Observatory staff and scholars share their ongoing work and research with the scientific community around the world. 2019 was also a year rich in more popular publications including the biography of one of our founding fathers.

BOOKS

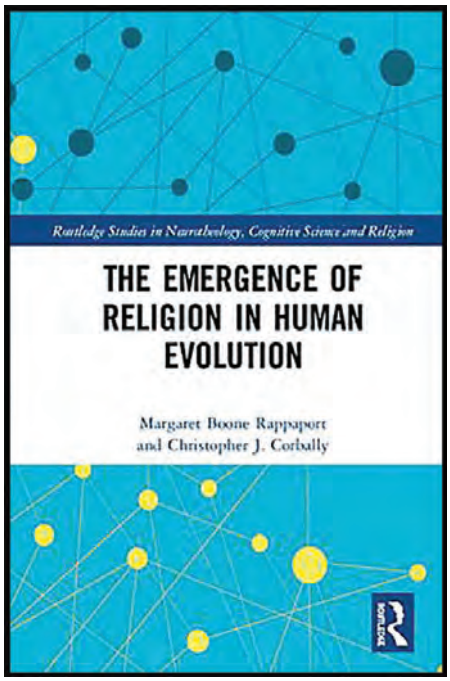
Decoding the stars: a biography of Angelo Secchi, Jesuit and scientist



Ileanna CHINNICI's opus on the life and work of Jesuit Father Angelo Secchi (1818-1878) was a major publication for the Vatican Observatory this year. Published by Brill with a forward by Guy CONSOLMAGNO, CHINNICI's biography provides an invaluable account of Secchi's life and work-something that has been sorely lacking in the English-language scholarship. Moreover, it is especially stimulating for those interested in the evolution of astrophysics as a discipline from the nineteenth century onward.

Despite his eclecticism, reminiscent of the natural philosophers of the seventeenth and eighteenth centuries, Secchi was in many ways a very modern scientist: open to innovation and cooperation, and a promoter of popularization and citizen science. Secchi also appears fully inserted in the cultural context of his time: he participated in philosophical and scientific debates, spread new theories and ideas, but also suffered the consequences of political events that marked those years and impacted on his life and activities.

The Emergence of Religion in Human Evolution (ERHE)

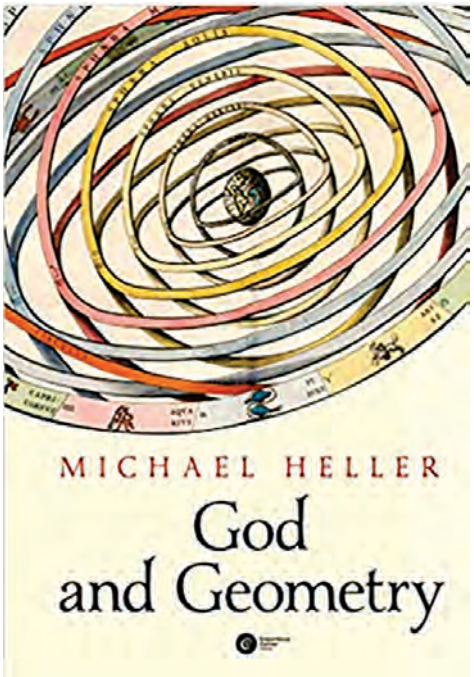


Religious capacity is a highly elaborate, neurocognitive human trait that has a solid evolutionary foundation. This book uses a multidisciplinary approach to describe millions of years of biological innovations that eventually give rise to the modern trait and its varied expression in humanity's

many religions. Author's Margaret Boone Rappaport and Christopher J. CORBALLY present a scientific model and a central thesis that the brain organs, networks, and capacities that allowed humans to survive physically also gave our species the ability to create theologies, find sustenance in religious practice, and use religion to support the social group. Yet, the trait of religious capacity remains non-obligatory, like reading and mathematics. The individual can choose not to use it.

A number of books by Michael HELLER appeared in 2019, including new works, new editions, or new translations:

There are a plethora of works on the history of geometry, both comprehensive and focused on individual periods. There are also plenty of course books in the history of philosophy, and no fewer course books and monographic works on the history of the Christian dogma. In *God and Geometry: When Space was God*, translated by Piotr Krasnowolski, Copernicus Center Press, Kraków 2019, HELLER is keen to see what you can find out studying works of both the types, something that has never been tackled straightforwardly in any of them. Making no claim on completeness, the book succeeds in paving the way and grasping a handful of ideas that are hidden from the view while the reader examines one side of this conjunction.



Other publications include:

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HELLER, M. (2019). *10.30 Chez Maximilien*, trad. Cecilia Bogdali, Éditions Croix du Salut, in French.

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HELLER, M., and Życiński, J. (2019). Dylematy ewolucji (Dilemmas of Evolution), 5th enlarged edition, Copernicus Center Press, Kraków, in Polish.

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BOYLE, R. P., Straižys, V., CORBALLY, C.J., Černis, K., Kazlauskas, A., JANUSZ, R., Maskoliūnas, M., Zdanavičius, J., Macijauskas, M., Wyrzykowski, Ł., Zieliński, P., Rybicki i K.A., Raudeliunas, S. (2019). „Interstellar Extinction in the Direction of the Cyg OB7 Association and the Open Cluster IC 1369 and the New Parameters of the Cluster".

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CONSOLMAGNO, G. J. (2019). As it is in the heavens. *The Tablet*, 273, January 26, 32.

CONSOLMAGNO, G. J. (2019). Double rubble. *The Tablet*, 273, February 23, 30.

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CONSOLMAGNO, G. J. (2019). Serendipity in the stars. *The Tablet*, 273, April 27, 32.

CONSOLMAGNO, G. J. (2019). Astral food for our souls. *The Tablet*, 273, May 25, 32.

CONSOLMAGNO, G. J. (2019). Crowded space. *The Tablet,* 273, June 22, 30.

CONSOLMAGNO, G. J. (2019). The Moon shines bright. *The Tablet,* 273, July 26, 32.

CONSOLMAGNO, G. J. (2019). The story of God. *The Tablet,* 273, August 24/31, 32.

CONSOLMAGNO, G. J. (2019). Interstellar interlopers. *The Tablet,* 273, October 5, 32.

CONSOLMAGNO, G. J. (2019). God in his heavens. *The Tablet,* 273, November 52, 32.

CONSOLMAGNO, G. J. (2019). Foreword. In CHINNICI, I., *Decoding the Stars, A Biography of Angelo Secchi, Jesuit and Scientist*. Leiden/Boston: Brill. pp. vii-viii.

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CONSOLMAGNO, G. J. (2019). Pale lamp of our dreams. *L'Osservatore Romano (English Edition)* 52, 29. 19 July, pp. 6-7; Pallida luce dei nostri sogni. *L'Osservatore Romano* 159, 164. 20 July, pp. 1-2.

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CONSOLMAGNO, G. J., Davis, D. M. (1989; fifth edition, 2018). *Turn Left at Orion: hundreds of night sky objects to see in a small telescope—and how to find them*. Cambridge: Cambridge University Press, 256 pp.

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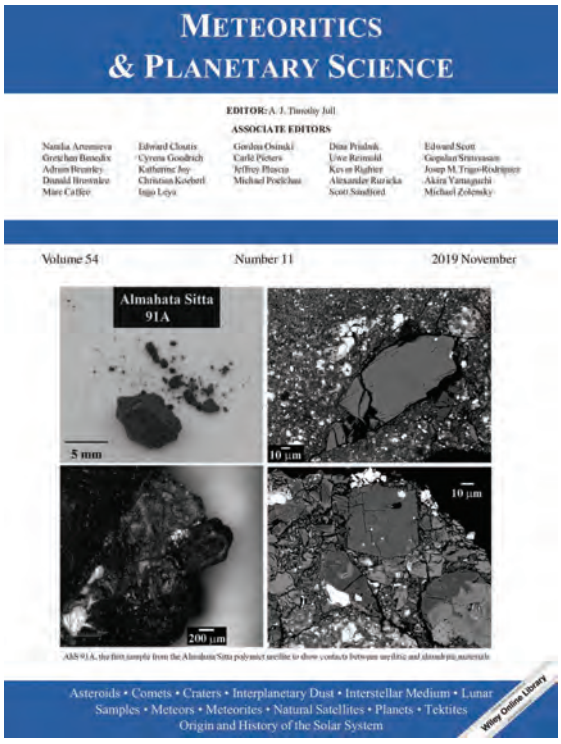

Macke was a coauthor of a paper featured on the cover of the November 2019 issue of Meteoritics and Planetary Sciences

Chapter SEVEN Visitors

It is always a pleasure to welcome academics, scientists, students and our generous benefactors to our facilities in Castel Gandolfo and Tucson. In 2019 we were also grateful to have hosted so many friends, family members and men and women religious. We welcome you all.

Visitors to the Specola for scientific purposes include:
Members of the IAU Executive committee; Deana Weibel, of the Grand Valley State University; Dr. Francis Thackeray, U. of Witwatersrand, Johannesburg South Africa; Michael T. Kezirian, International Space Safety Foundation; Gregory Quarles, The Optical Society; Giuseppe di Persio, INAF/IAPS; Livia Giacomini, INAF/IAPS; Rev. Timothy Thomson, Drexel University; Gennaro Stammati, Commissione Scienze e Fede di Verona, and Astrofili of Verona; Christer Sandin, Leibniz-Institut für Astrophysik Potsdam; Lars Mattsson, Nordic Institute for Theoretical Physics ; Paolo Ventura, INAF.

Vatican Groups hosted at the Specola include:
Hon. Castilla Gingrich, Ambassador of the US to the Holy See; Members of the Vatican's Congregation for the Doctrine of the Faith (CDF), led by Cardinal Luis Ladaria Ferrer, S.J.; Members of the Dicastery for Laity, Family and Life; Vatican Patrons of the Arts; Jesuit Refugee Service International Development Group.

Large Group visits hosted at the Specola, with didactic / academic sessions include:
DePaul University; DePauw University; Loyola University Chicago; Corpus Christi College; Emory University; Portuguese College Seminarians, St. Ignatius College Preparatory School; Canadian student group (via Adam Hincks); Boston College; Society of Italian Science Journalists; Lay Center of Rome; Lipscomb University; Liceo Classico di Albano; Scuola Superiore Rosselli di Aprilia; a group of 20 students (in the sciences) from Drexel University, Philadelphia, PA, USA; students from Walsh University, Canton, OH, USA; students from Belmont University, Nashville, TN, USA; Rev Michael Kesicki and students, Gannon University; Raymond Carlberg, University of Toronto; Matthew Daniels, Georgetown University; Jan Tillman and 25 students, Gymnasium Marianum, Warburg, Germany; Duilia Demello, Catholic University of America; Mathias Beck, University of Geneva; Nine students, Russell Berrie Fellows in Interreligious Dialogue, Angelicum; Students from the "Liceo" di Frattamaggior, Naples, Italy.

Individual / small group visits hosted at Specola
Cork Astronomy Club; Same Hale and his wife; Peter Juhasz, PhD student at Oxford; Friends of Katie Steinke; Jim McGee and Family; Ben Jansen and Family; Jill Nichols, artist.

Religious Groups hosted at Specola include: The Pontifical German College; Little Sisters of the Poor; North American College seminarians; Franciscan Sisters of the Eucharist; Jeffrey Kloha, Museum of the Bible; Fr. Lawrence Machia O.S.B, St. Vincent Archabbey; the sisters "Apostole della Vita Interiore" in June, in August the Salesian Novices and other sisters of the Salesian Noviciate in Castel Gandolfo.

The VATT-PEPSI-TESS Survey collaboration, Klaus Strassmeier, Michael Weber, Ilya Ilyin, Arto Järvinen, Silva Järvinen, Thomas Granzer, Thorsten Carroll, David Gruner, and Matthias Steffen, as well as BOYLE, September 17-19, with many thanks for help and advice to Federico, Assunta, Antonio, and Romano.

TUCSON

Visitors to the Specola for Scientific purposes include:

Dr. Dragana Ilić, alumna of VOSS 2001, University of Belgrade; grad students Martin Millon and Aymeric Galan of EPFL, Switzerland;

Alison Rose, Inigo Films, Toronto, Canada; Marius Maskoliūnas, Bob Trembley.

Religious Groups hosted at Tucson include:

St. Francis de Sales and Sacred Heart Seminaries, Wisconsin

Visits by Vatican Observatory staff to other institutions for scientific purposes:

BROWN visited Liebniz Institute for Astrophysics, Potsdam (AIP) in Potsdam, Germany in April and paid periodic visits to Monte Porzio INAF Observatory in the Castelli Romani region of Italy for seminars and collaboration.

From July 28 to August 5, **GABOR** took part in the 36th Ebicycle, a 7-day, 350-mile cycling tour of observatories and astronomy sites, each year alternately in Bohemia, Moravia, and Slovakia. This was the 11th time he joined the group of 50 professional and amateur astronomers for the event. He visited observatories and planetaria in Veselí nad Moravou, Trebic, Zdar nad Sazavou, Vranove, Boskovice, and Prostejov (all in the Czech Republic).

GABOR visited Paris on September 23-24 and spoke with Pierre Lena (member of the French Academy and the Pontifical Academy of Sciences), Jacques Arnould (CNES), Stephane Mazevet, Claude Catala (President of the Observatory of Paris) and Alain Leger (IAS). He visited and gave a talk at Raytheon Vision Systems, Goleta, California on October 18. He participated in the first meeting of the Alliance of Historical Observatories (AHO) at Mt Wilson Observatory, June 15-16, and in the second AHO meeting at Palomar Observatory, October 19-20.

GIONTI visited the theoretical physics department of the University of Mainz, Germany January 13-25, hosted by Prof. Martin Reuter. He also visited the Korean Institute of Advanced Studies (KIAS) hosted by Dr. Miok Park in February and September-October, 2019 hosted by Prof. Jaewan Kim. He also spent some time at the Catania Astronomical Observatory April 1-7, hosted by Dr. Alfio Bonanno.

In November, Br Consolmagno hosted students of the Russell Berrie Fellows in Interreligious Dialogue from the Pontifical University of St. Thomas Aquinas (Angelicum)