SPECOLA VATICANA
VATICAN OBSERVATORY

say "Pepsi, please"

The Vatican Observatory

ANNUAL REPORT 2021

Annual Report 2021

Vatican Observatory Staff

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- DANTE MINNITI
- MARIA ELENA MONZANI
- GIUSEPPE TANZELLA-NITTI

Other Scholars:

- CLAUDIO COSTA - *Technical Expert*
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Cover: *Spectra colors from N. A. Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF; image of Pepsi sign, Klaus Strassmeier*

Photo pages 4-5: *Credit Joe Hoscheidt*

Editor: Emer McCarthy
Design, layout and digital edition: Antonio Coretti

Vatican Observatory Publications

CHAPTER ONE

From the Director

How can we show the world the ways that the Church supports our science? The need remains the same, even as the technology changes.

Weaving a New Web

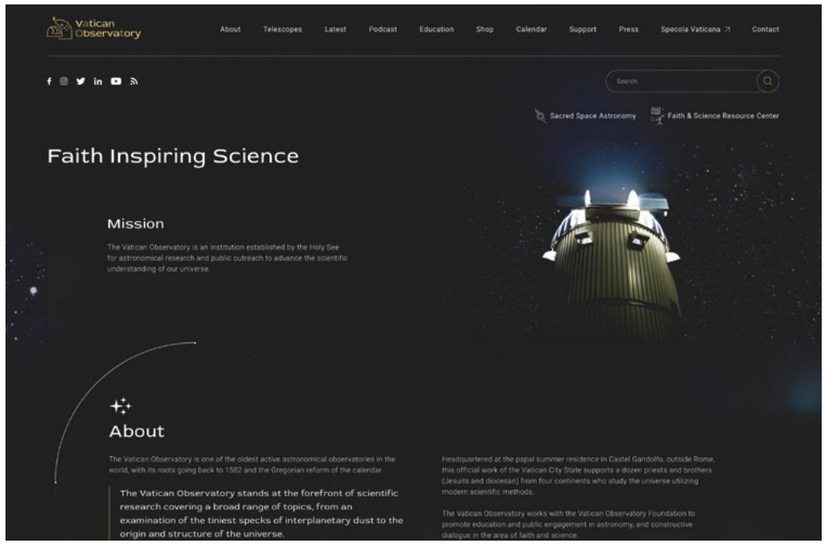
"…that everyone might see clearly that the Church and her Pastors are not opposed to true and solid science… but that they embrace it, encourage it, and promote it with the fullest possible dedication."

So wrote Pope Leo XIII in his *Motu Proprio* of March 14, 1891, establishing the Vatican Observatory. Ever since then that phrase has been our mission statement.

That mission places two tasks before us. The obvious one is to produce the good and solid science that the Church can embrace, encourage, and promote. But the other and equally important task is to be sure that "everyone might see clearly" how the Church embraces this science.

The science we do today goes far beyond what could have been imagined 130 years ago. So do the ways we have today to reach everyone with our story. More than a year ago, Fr. Justin Whittington SJ who handles all the day to day tasks of the Vatican Observatory Foundation (of which I also serve as president) submitted to the Templeton Foundation a hundred-thousand-dollar proposal to completely revamp the Foundation's internet presence. They agreed. Thus in 2020 we contracted with Longbeard, a web design company with a long history of collaborating with Vatican offices, to start designing a new way we could present ourselves to the online world, starting with a completely new web site. That site was launched with some fanfare on April 1, 2021.

As it happens, I've been working with computers since my undergraduate days at MIT and I even had an early taste of what would become the internet back in 1973 with a prototype educational network run out of the University of Illinois called PLATO (Programmed Logic for Automated Teaching Operations). I've used ARPAnet, BITnet, NetScape; I looked myself up on search engines (remember Alta Vista?) before they were called search engines. I thought I knew computers pretty well. And I have a background in journalism, an interest that I inherited from my father who was himself



Br Guy and the newly restored 1891 Carte du Ciel telescope, a symbol of the Vatican's longstanding support (see chapter 4).

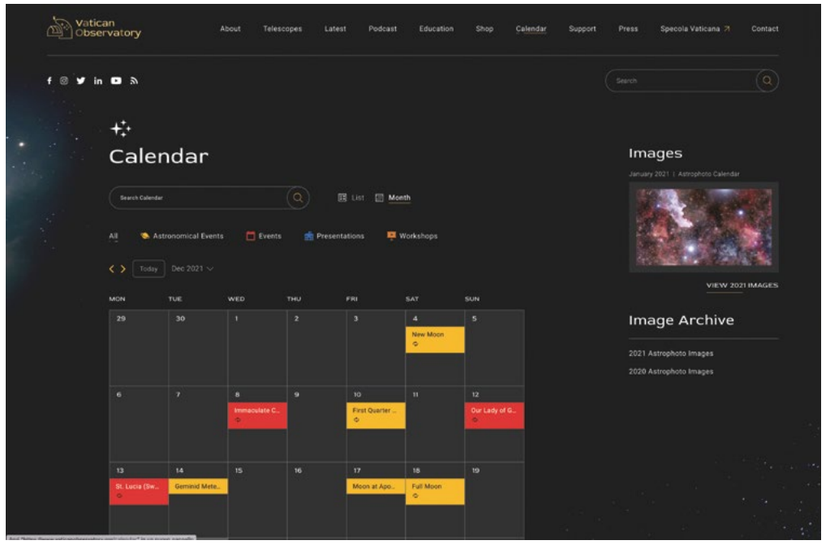
an early supporter of the Public Relations Society of America. I thought I knew the ins and outs of public outreach. Ha!

Longbeard does this for a living, and obviously they've kept up to date on what modern design looks like. Their ideas and recommendations surprised me… and humbled me, as over and over they demonstrated that they knew their stuff better than I did.

Before we hired them, we had a perfectly workable web site, and a nice little blog site as well. I thought we could just touch them up a bit.

But instead, Longbeard came up with a striking new and original design for our site. From the background colors to the choice of font styles, it conveys our roots in astronomy, our deep history, and our cutting edge research.

Longbeard pointed out that what we had been doing on our old site was both old-fashioned and inefficient. For example, our old site used a completely forgettable URL name (which mentioned neither Vatican nor observatory). Thus Longbeard's first recommendation was to adopt a new and more obvious URL: *www.VaticanObservatory.org* for our new site. The site is maintained by the Foundation, but now the content is focused on the Observatory. As the Longbeard folks reminded us, the job of the Foundation is to support the Observatory, not brag about itself. (Our official Vatican site ends with ".va" to differentiate it from the Foundation's site at ".org".)



And the blog site looked like it was about ten years out of date. (It was. Blogs are so 2010!) Instead, Sacred Space Astronomy has become more than a blog; it's an online community where we can present current articles on the latest in astronomy, on our history as one of the oldest astronomical institutions in the world, and on our reflections of what it is like to be a person of faith immersed in the study of God's creation. Once a month — or, more accurately, once every full Moon — our members get to join in on a Zoom call with a staff member or associate of the Observatory. As a part of this, we now link to a site that will print on demand the Vatican Observatory Foundation's logo on coffee cups, tee shirts, and the like. It's a fun way to express your support for our work.

They also revamped our Faith and Science resource pages.

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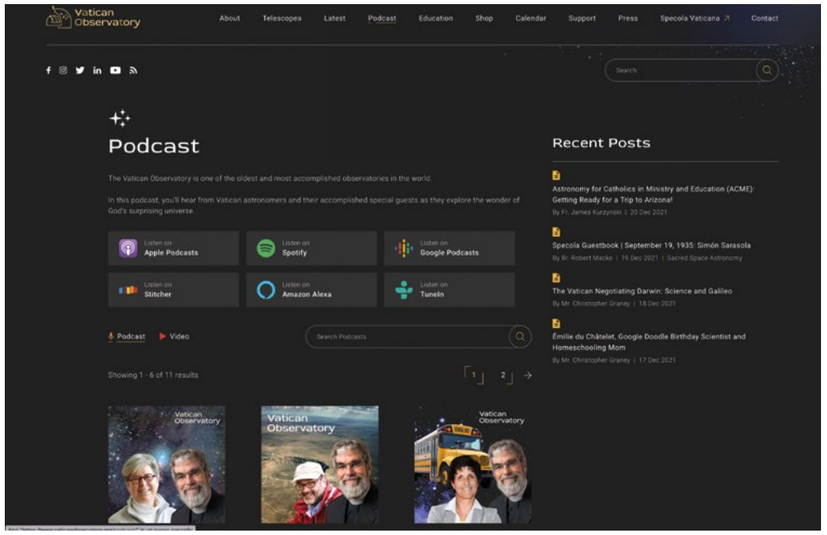
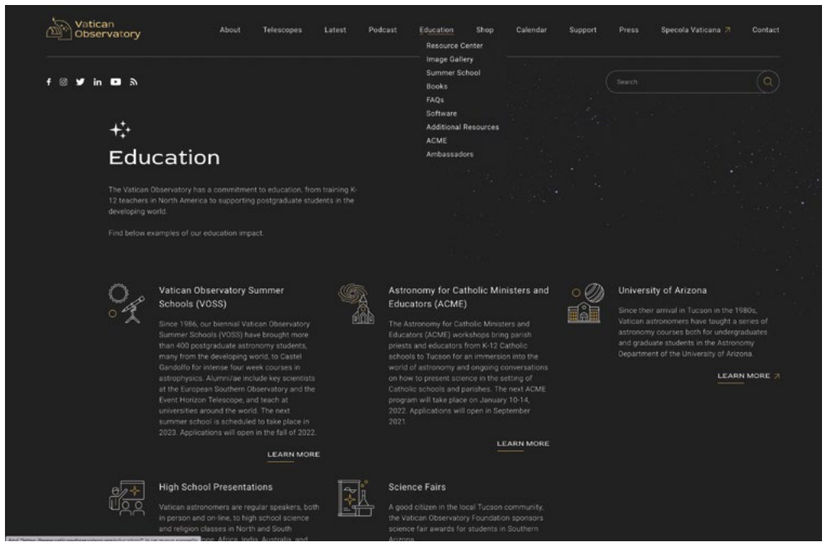
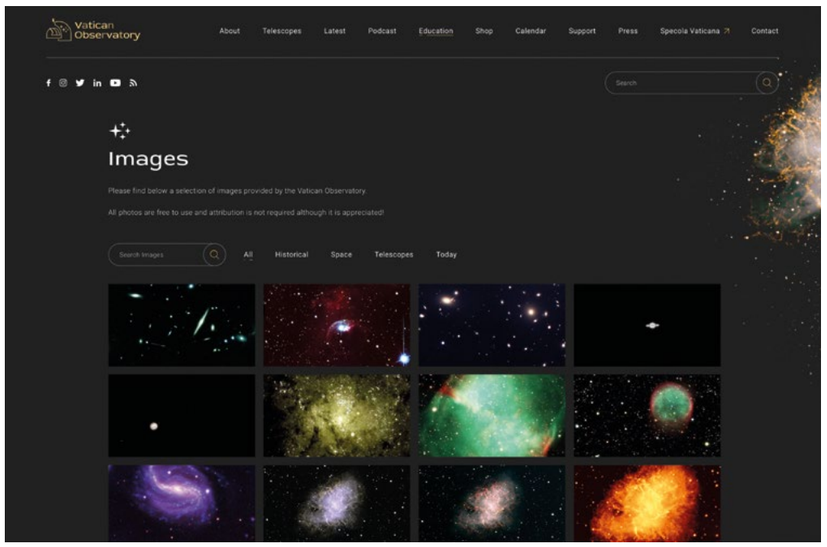






There we now have organized by topic and medium more than 500 resources — articles, videos, and links — that Catholic educators (and educated Catholics) can use to explore how faith and science interact. Likewise, the Longbeard people got us started on producing podcasts where we get to interview the scientists we know and admire, and spread their stories alongside ours.

But the heart of the site is the vast amount of information, from images to technical specs, about the Vatican Observatory. It includes short biographies of our staff, descriptions of the different telescopes both historic and current, and images from those telescopes and from our long history, all available for download.

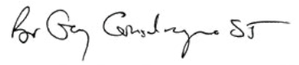
Since its launch our site has seen an increase in traffic and, what's more, an increase in interest from various news sources and other online sites. In particular, the American public radio network NPR had one of their most prominent European correspondents, Sylvia Poggioli,out to visit our site in Castel Gandolfo and interview us. That program resulted in a wonderful spike in visitors to the site, who spent a few seconds before moving on but actually stayed to read what we had to say. And in many cases, those visitors also joined our Sacred Space Astronomy group. The number of subscribers has doubled since our launch date.

Having a fully functional web site with the various analytical tools that come along with it is also a way that we can see who's been looking for us, and what bits of our story they find especially interesting.

My father, the public relations expert, had always emphasized to me that good PR was a two-way street. It's not enough to tell our story to the world, we also have to listen to what the world wants to tell us… even if, indeed especially if, it is not what we were hoping to hear. To that end, our adjunct scholar Chris Graney has also taken on an important role in analyzing the analytics and seeing where we could be doing a better job of finding the people who want to find us.

Of course, a good web site is only one part of education and public engagement. That effort requires so much more. Within this annual report, as has been our custom for a while now, you will find a full chapter about all the things that all of us have been doing all around the world, even in this age of Covid, to show the world how the Church supports science.

But our story depends on two things that we can never forget. The first is that without the good science that we do every day, we'd have no story to tell. Of course that makes up the heart of this annual report. And the second is that without the support of the Church we would have no reason to tell this story. The story of science is the story of creation; but the story of creation derives its meaning from its Creator.



Br. Guy Consolmagno, SJ
Director, Vatican Observatory

Personnel News at the Vatican Observatory in 2021

New Adjunct Staff:

In November, the Vatican approved the appointment of **Maria Elena Monzani** as an Adjunct Scholar of the Vatican Observatory. Dr. Monzani works at the National Accelerator Lab at Stanford University, SLAC, as the deputy operations manager for computing and software on the LUX-ZEPLIN Dark Matter Experiment. She is also active in the Archdiocese of San Francisco, where she gives popular presentations on Faith and Science.

Dr. Monzani is originally from the Milan area and obtained her Laura/MSC degree from the Università degli Studi di Milano; she then earned her PhD jointly from there and the Université Paris VII - Denis Diderot in 2005 for her work on solar neutrinos. After working at Gran Sasso and a term as a postdoc at Columbia University, she moved to SLAC in 2007.

She joins a growing community of cosmologists at the Specola, including GIONTI, GALAVERNI, and HINCKS. Dr. Monzani's research in dark matter builds on the notable discoveries of the late Dr. Vera Rubin, herself a longtime friend of the Specola and instructor at our first Vatican Observatory Summer School in 1986.

In Memoriam:

Brother John Hollywood, who served both the Jesuit Community of the Vatican Observatory and the Vatican Observatory Foundation as minister and treasurer for many years, died on October 31, 2021, at the age of 83. Br. John started with the Vatican Observatory Foundation in 1987, a year after the Foundation started; he retired from the VOF Board in February 2013, after leaving Tucson.

John B. Hollywood, SJ, was born on May 4, 1938, in New Philadelphia, Pennsylvania. He entered the Society of Jesus in 1957 and pronounced his final vows in 1971. Along with his work at the Vatican Observatory, John Hollywood served many of the Maryland Province's schools and universities over his more than six decades in the Society of Jesus. He was Knight Commander of the Holy Sepulcher, and an active member of the Ancient Order of Hibernians.

In the memorial page published on the Vatican Observatory Foundation's web site, Fr. Chris Corbally recalled Brother John:

Three characteristic occasions remind me of Brother John as an accomplished facilitator of the Vatican Observatory's mission.

The first was in the summer of 1986 when he was minister at our headquarters in the Papal Palazzo at Castel Gandolfo. He had been invited, maybe challenged, by Father George Coyne, the then director, to manage lunch for the very first Vatican Observatory Summer School.

John co-opted the help of his fellow Maryland Province Brother, James Lemon (a.k.a. Juice), and together they contrived for a month in a far-from-ideal kitchen to produce lunch on the adjacent terrace for the 25 students, the three professors, and sundry others including those from the Jesuit community who joined the pleasant gathering.

Goodness! Talk about working miracles, all with much patience and humor from the John-Juice combination. In subsequent repeats of the Summer School, outside catering was found to be the less stressful solution.

The second occasion was John's commission, also from George Coyne, to set up during 1989 to 1990 the new residence for the portion of the Vatican Observatory's Jesuit community in Tucson. Now, building the extra wing along the east side of the property was right up John's street. Furnishing this wing and the rest of the house needed some special expertise.

Whom else should John best engage to advise on this but the Vatican Observatory Foundation's tax accountant, Carla Keegan? Carla did such a quality job that a couple of years later, when I was needing to furnish the Thomas J. Bannan facility for the Vatican's new Alice P. Lennon telescope on Mount Graham, John suggested I too call on her expertise. Maybe John, like me, then just followed Carla around Tucson's furnishing stores with a checkbook in hand. Much of the furniture is still giving good service nearly 30 years later despite hard use. John would always buy quality.

My final occasion with John also involved furniture, kind of. John used to hunt bear in Maine with one of his brothers, I think Patrick. Instead of making yet another bear rug from the skin, John had one of them mounted in a standing, rather threatening pose, ideal for enhancing the atmosphere of his office. The bear was shipped to Tucson, but in a case far too tall to fit even into one of our mountain SUVs.

Undaunted, John remembered that the Astronomy Department at the University had a pickup truck for running errands around town. While the staff member, who kindly arranged for John and me to borrow the truck, was running through possible explanations to authorities of how a mounted bear was essential to our astronomical research, John and I went out and successfully conveyed the beast from the road transport company's depot back to his office at our residence.

With John, you never knew what the new enterprise would be; but he could always make it work. God's peace to John now from his labors."— Chris Corbally, Nov. 8, 2021

Two longtime collaborators of BOYLE and JANUSZ from the Vilnius Observatory in Lithuania have died this past year; another passed in late 2019.

Kazimieras Zdanavičius, a Lithuanian astrophysicist who worked closely with BOYLE, JANUSZ, and their collaborators, died on November 12 at the age of 83. Educated at Vilnius University, since 1990 he had worked there at the Institute of Theoretical Physics and Astronomy.

With V. P. Straižys (see below), he developed the seven-color photometric system for stellar parameters (Vilnius Astrophotometric System) that figures prominently in the work of BOYLE and JANUSZ (see the 2019 Annual Report). He investigated stellar physical parameters and the distribution of interstellar material in dozens of galactic regions, clusters, and associations, publishing more than 100 scientific papers.

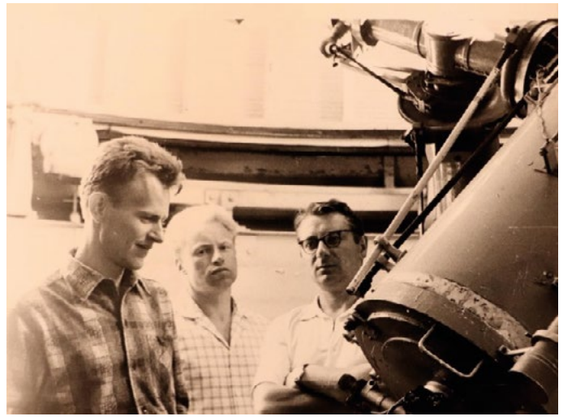
Zdanavičius was also a devout Catholic, active in a rosary community that met regularly at the Vilnius Cathedral.

Vytautas Pranciškus Straižys died on December 19 in Vilnius at the age of 85. Born in Utena, Lithuania, he began studies in the physics department of Vilnius University in the mid 1950s and in 1959 joined the Institute of Theoretical Physics and Astronomy, eventually reaching the position of chief researcher. His doctoral thesis in 1963 was on the topic of developing a multifilter system for classifying stellar properties, work with Zdanavičius (see above) that he would carry on for the rest of his life.

As described in the 2019 Annual Report, he and his work first came to the attention of Fr. George Coyne in 1978. Excited by this new system, Coyne encouraged Boyle to look into this system when he first arrived at the Specola in 1981. Thus began a collaboration that has lasted for forty years (and is still ongoing), including several visits to the Specola by Straižys, his students, and his collaborators.

Straižys was awarded the Officer's Cross of the Order of the Duke of Lithuania in 2003, and twice awarded the Lithuanian Science Prize, in 1973 and 2004. He served as the editor of the *Bulletin of the Vilnius Astronomical Observatory*, the scientific journal *Baltic Astronomy*, and the popular magazine *Lithuanian Sky*. In 2002, asteroid 68730 Straizys was named in his honor.

Along with more than 500 papers and articles he also wrote a number of textbooks and popular books on astronomy. This interest in sharing astronomy with the general public was just one side of his generous personality. The Specola astronomers remember him as a person full of joy and life, gentle and always encouraging. "If we made a mistake," one of them recalls, "he wouldn't accuse us directly; instead he would just say, 'Well, something must have gone wrong…' "



From left: A. Bartkevičius, K. Zdanavičius, V. Straižys at the Vilnius Observatory 48 cm Grubb telescope in 1968.

We have only learned recently of the passing of **Ajoy Dasgupta**, a longtime scientific collaborator and friend of the Vatican Observatory. He died on November 28, 2019, in Cardiff, Wales, at the age of 84.

Dasgupta worked in the 1980s and into the 1990s with BOYLE and his collaborators on the computer processing and analysis of CCD photometric imaging observations. Boyle recalls, "I believe it was Dr. Kashi Nandy of the Royal Observatory Edinburgh (Scotland) who introduced Ajoy Dasgupta to Filippo Smriglio, and subsequently to Dr. George Coyne and me."

Their fellow collaborator Filippo Smriglio adds, "Ajoy was more like a brother to me. He was a person who was absolutely honest and generous and the best of fellow workers, but so much more. In Edinburgh he taught mathematics in a Catholic school. He took his PhD with Kashinath Nandy; the topic of his thesis was interstellar matter. In the mid-80s Dr. Nandy introduced him to our group, formed by Straizys, Nandy, Boyle and Smriglio with a program centered on the use of the Vilnius system for intermediate band photometric classification."

In the 1990s he was employed at the Institute of Astronomy, University of Rome "La Sapienza," with an affiliation with the South Glamorgan Education Department, Cardiff, UK. The latter became his full-time affiliation in 2001.

CHAPTER TWO

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say “PEPSI, please”

Since 2018, thin fiber optic cables have stretched underground from the Alice P. Lennon Telescope at the Vatican Advanced Technology Telescope facility on Mt. Graham, to the pier base of our neighbor, the Large Binocular Telescope. It connects the VATT to the Potsdam Echelle Polarimetric Spectroscopic Instrument – PEPSI – built by the Astrophysics Institute in Potsdam, Germany (AIP). But really, it’s the search for new knowledge that ties us together.

Discovering new worlds is one of the most exciting astronomical endeavors of our time. However, a press release simply saying that there is a planet orbiting one of the stars in our region of the Milky Way Galaxy is unlikely to make headlines *unless* it comes with a pretty color picture of an “artist’s impression” of the exoplanet in question, or of an alien landscape on its surface. That’s what really stimulates the imagination.

Of course, when you discover an exoplanet, you cannot include a pretty “artist’s impression” in your press release unless you already have a good idea of the properties of the planet… for instance, how big and how hot it might be. Otherwise, these images would just be pure fiction.

But how do you measure the properties of a planet you cannot actually see? It is all deduced from the properties of the planet’s star. The planet’s mass and diameter are obtained as percentages of the star’s mass and diameter. The planet’s temperature is derived from the star’s temperature. The planet’s age is a function of the star’s age. And so on…

For example, suppose you discover an exoplanet using the transit method. If you know the star’s classification you can estimate its diameter, its temperature, and its mass.

By seeing how much the light of the star dims when the planet crosses in front of it, you have a measure of the exoplanet’s diameter as a percentage of the host star’s diameter.

By timing the period between dips, you measure the planet’s orbital period. Knowing the star’s mass, you can use the planet’s orbital period and Kepler’s third law of orbits to calculate the planet’s distance from the host star.

If you know the star’s temperature, then knowing how far the planet is from the star, you can estimate how much of its heat reaches the planet’s surface. That tells you the planet’s average temperature.

Meanwhile, once you have discovered that a given star has a planet, you can observe that star in detail to see how the colors of the star shift as the planet pulls it back and forth. The strength of the planet’s pull on the star tells you the planet’s mass. Its mass, divided by the volume of the planet (remember that the transits gave us a measure of its size) tells us its bulk density. From that you can determine the basic type of the planet: gas giant, ice giant, rocky planet, etc.

Thus, everything we think we know about the planet depends on knowing its star in detail: its class, its size and temperature.

How do you determine this? The answer is high-resolution spectroscopy.

The Spectrograph

It so happens that one of the most powerful spectrographs in the world lives in the pier of the Large Binocular Telescope (LBT), our neighbor on Mt Graham. It is the Potsdam Echelle Polarimetric Spectroscopic instrument (PEPSI). It was constructed to analyze the light captured by the two 8.4m (27.5ft) mirrors of the LBT. However, the LBT has many instruments and many different users. That means that most of the time PEPSI would sit idle.

And so, in 2014, Paul Gabor began negotiations with the AIP to develop a plan to feed PEPSI with starlight captured by the VATT. The light is fed via a fiber optic cable, about 500 meters or a third of a mile long, from the VATT to PEPSI in the LBT building. Of course, the collecting area of the VATT’s primary mirror is just 2.4% of the LBT’s combined mirrors, and the fiber attenuates the light even further; but even so, for brighter stars, enough light arrives at PEPSI for its sensitive detectors to do their work.

Like a prism splits up sunlight into its various colors, a spectrometer like PEPSI separates the light of a star into its component wavelengths. You can see this in the VATT spectrum of the star KappaGem in Figure 1.

But a closer look at the rainbow of light reveals thin dark lines amid the colors, which correspond to the dips in the spectrum, its lines. These spectral lines are caused by the absorption of light from chemical elements present on the outer envelope of the star. Each chemical element, when heated in its gaseous form, produces a spectrum with lines particular to it; every element’s spectrum produces a unique “fingerprint” spectrum by which it can be identified amongst the spectral lines of different objects.

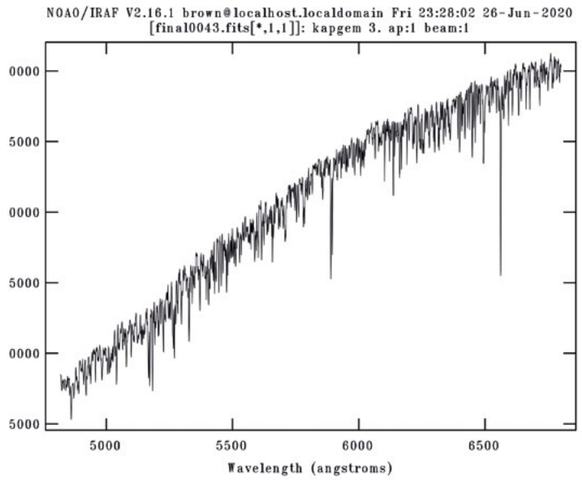

Figure 1: Spectrum of the star KappaGem taken at the VATT.

(In fact, one of the earliest works of the Vatican Observatory when it moved to Castel Gandolfo in the 1930s was the Spectrochemical Laboratory, where the precise spectra of such gases were measured, element by element. The tables of spectra they produced back then form the basis of interpreting stellar spectroscopy today.)

The actual light within dark lines of a spectrum (see Figure 2) can be measured precisely. When you plot the brightness of the star against the wavelength of the light it emits, these lines show up as dips in the curve. But the dips tell us more than just what chemicals are present. The width and depth and shape of the dips tells us the star’s surface temperature, its pressure and density, its magnetic fields, its stellar winds. And measuring how the precise wavelength of the dips change as the star moves, tells us the mass of the planet that is tugging at the star.

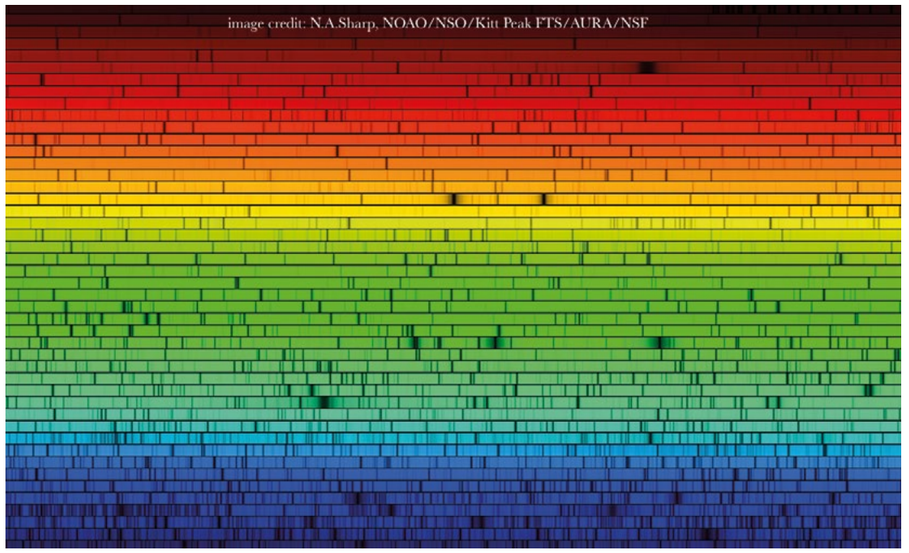

Figure 2: Spectra colors; from N. A. Sharp, NOAO / NSO / Kitt Peak FTS / AURA / NSF.

Can we learn more?

The main scientific question that the VATT-PEPSI survey is trying to answer is, "what is the relationship between exoplanets and their host star(s) in a stellar system?" Beyond the basic parameters of the exoplanet's size and density, can spectroscopy of the host star tell us more about the planet?

Looking at stars to learn more about planets may seem like a case of comparing apples to oranges. However, we may use the colloquial expression that "the apple does not fall too far from the tree".

From observations of protoplanetary disks (Figure 3), which are stellar systems in the process of forming, it can be surmised that the star(s) and exoplanets in such a system have formed from the same "stuff", the same primordial cloud of gas and dust (Figure 4). Hence, astrophysicists speculate that there should be some relationship between the stars and the exoplanets that orbit around them, though the precise relationship is not well-known thus far.

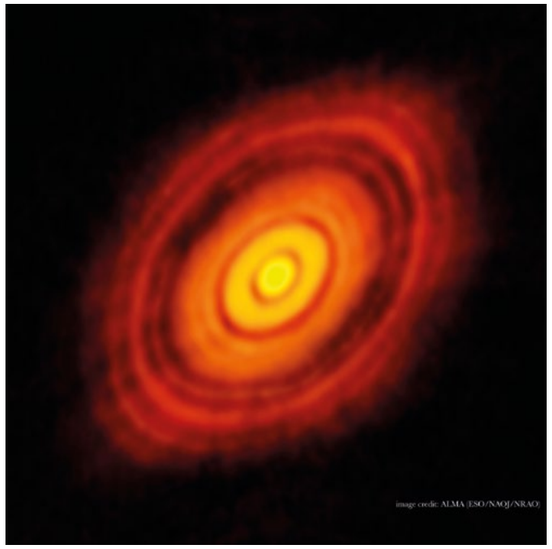

Figure 3: Protoplanetary disks can now actually be seen in our telescopes. This image comes from the Alma array of telescopes in Chile.

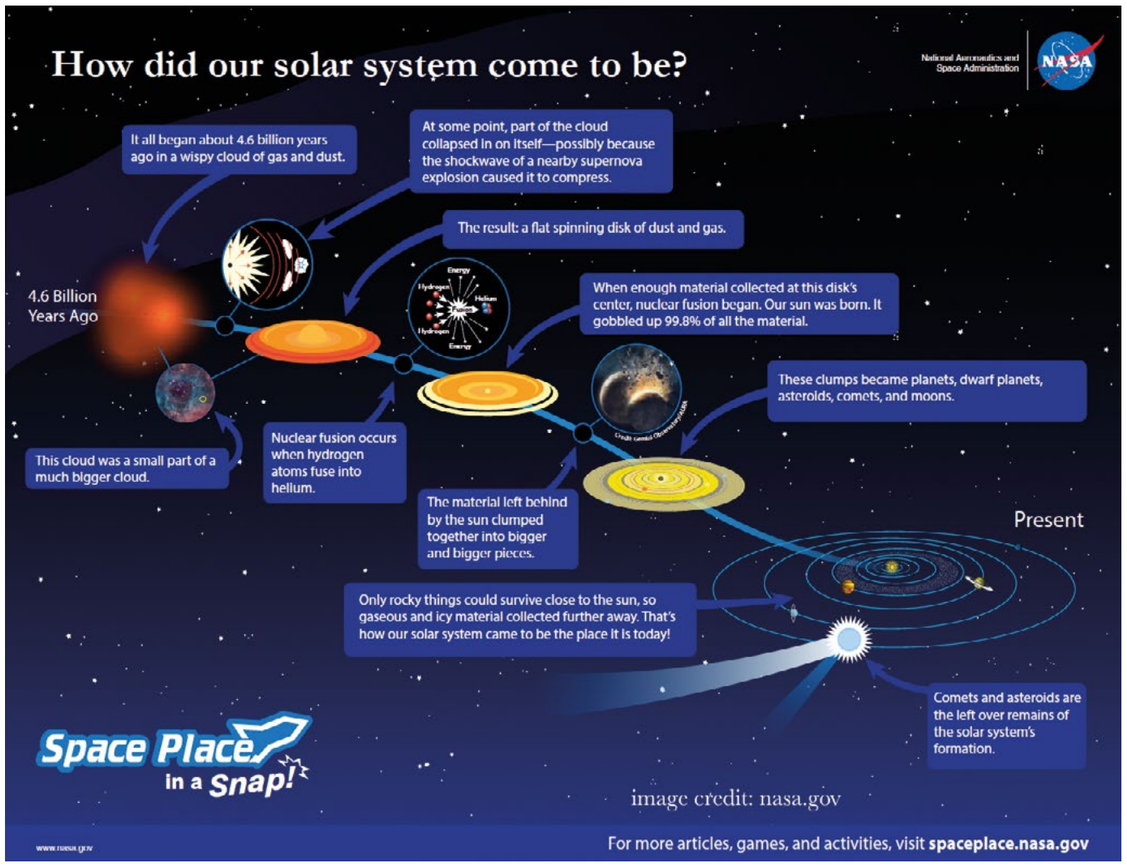

Figure 4: An illustrated description of how we think solar systems like ours are made, from the NASA web site spaceplace.nasa.gov

Of course, all of this is pointless if you don't know which stars to measure – which stars have planets. Currently, one of the most promising projects for exoplanet discovery is NASA's Transiting Exoplanet Survey Satellite (TESS). From its candidate stars comes the VATT-PEPSI-TESS Spectroscopic Survey, to supply solid information about some promising stars studied by TESS.

The basic goal of the VATT-PEPSI-TESS endeavor is to provide precise spectroscopic parameters for potential planet-host candidates for TESS. Thus over the past four years, Paul Gabor and David Brown together with the team from AIP, led by Klaus Strassmeier, have done many observations (Figure 5 and Figure 6) for the VATT-PEPSI-TESS survey.

Diet Pepsi: Reducing the Data

The direct data product of a night of observations for the VATT-PEPSI-TESS collaboration is the spectrum of star, which gives the amount of light emitted by a star at different wavelengths (frequencies/colors of light). As we have seen, an examination of the spectrum can then yield many properties of the star. What makes a PEPSI spectrum a very powerful tool is the amount of detail, or high resolution, that it can provide, as is seen in Figure 5.

So, how does one pull information out of a stellar spectrum? After the observations at the telescope are finished, the work of reducing the data from PEPSI begins.

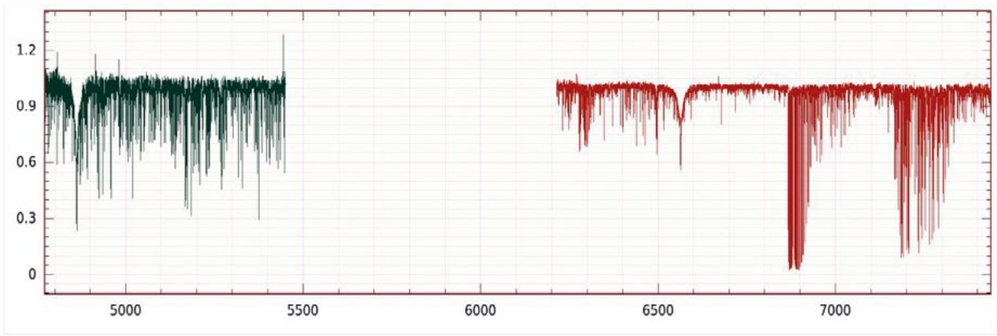

Figure 5: PEPSI spectral data, from Strassmeier, the PEPSI Blue Paper.

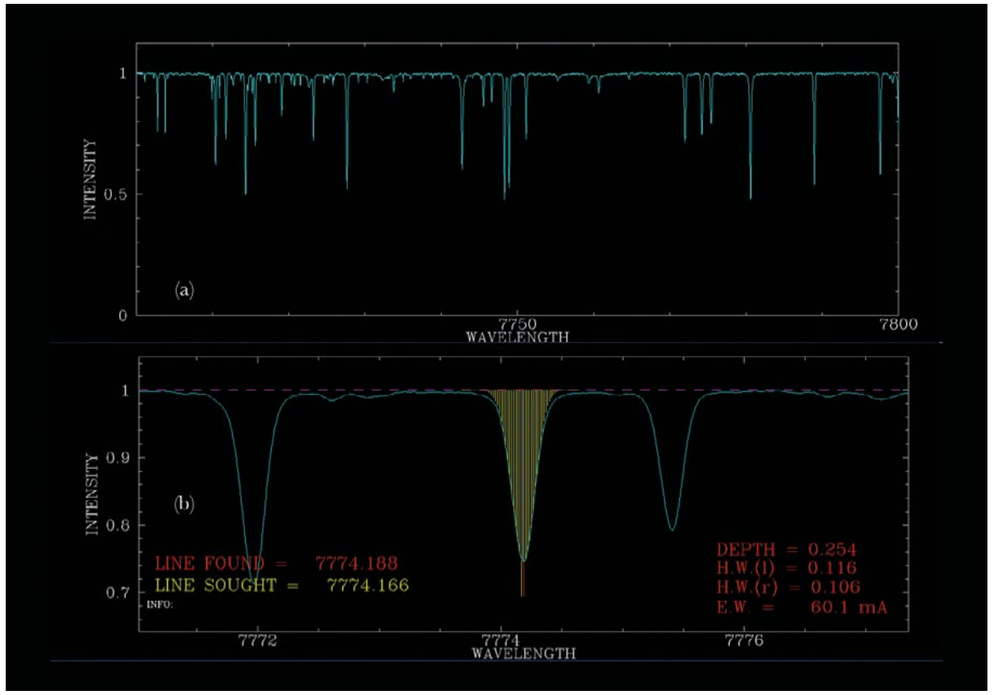

Figure 6: High resolution PEPSI data lines are fit and analyzed by BROWN and colleagues with advanced computer codes.

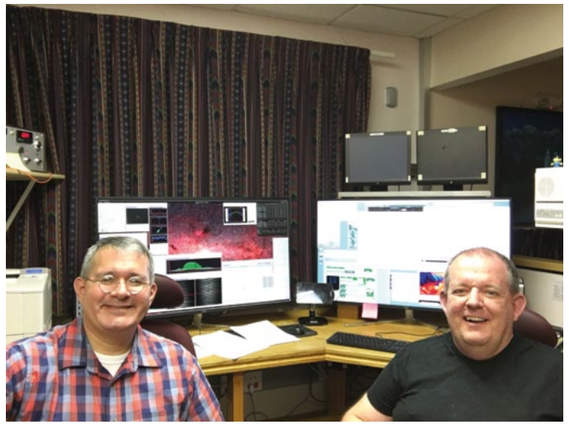

Figure 7: Brown (left) and Gabor (right) at the controls of the VATT.

First, the direct observation of a target star with VATT-PEPSI yields a raw spectrum. One must then extract the actual scientific spectrum from this, removing the effects of the atmosphere and of the instruments themselves, along with the relative motion of the star. This task done by one of the members of AIP, Ilya Ilyin. It yields the actual scientific data spectrum of the light of the star itself.

Another member from AIP, Michael Weber, then determines the basic stellar parameters from the spectrum: the surface temperature of the star, its gravity, its metallicity, and the microturbulant velocity of gases in outer regions of the star, amongst other parameters.

Once these parameters have been determined, it is then David Brown's responsibility to determine the chemical abundances of the star. How is this done? First, from the spectrum he selects certain well-defined spectral lines, corresponding to certain chemical elements. Next, he determines the strengths (equivalent widths) of such lines (Figure 6) with a computer code called SPECTRE. Then, with the help of a theoretical model of the star (MARCS), together with the equivalent widths of the star, another code (MOOG) is used to figure out the abundance of each chemical element. These are usually calculated relative to their abundances in the Sun.

In determining the chemical abundances of a particular star, our interest is primarily in the CNO elements – carbon, nitrogen, and oxygen; and the α-abundance elements such as Mg, Si, S, Ca, Ti, and also Fe (iron). The latter are important because they constitute the primary ingredients in rocks on rocky exoplanets, whereas the former are present in organic compounds.

Once again, assuming that there is a compositional link between a host star(s) and the orbiting exoplanets, deducing the abundances of such elements on the exoplanets in a generalized way can, in turn, contribute to speculation about other possibilities for such planets, including the possibility of life.

The Collaboration

The VATT-PEPSI-TESS Spectroscopic Survey is a collaboration between the Astrophysics Institute in Potsdam near Berlin (AIP) and the Vatican Observatory. The observing program comprises campaigns of about 50 nights around the Summer Solstice when the NEP is the highest in the sky. We started in 2018, and continued in 2019, 2020 and 2021. (As reported in last year's annual report, the 2020 campaign had a late start due to the COVID-19 lockdown, and then it was further hampered by smoke from the Bighorn Fire in the Santa Catalina Mountains.) The observations will conclude in 2022.

We have chosen 311 stars of interest, so that if or when TESS finds evidence for a transiting exoplanet hosted by one of these stars, we will be able to provide their detailed characteristics. Which stars do we choose? TESS will study the whole celestial sphere, but it will survey some regions more often than others. The best covered regions are the ecliptic poles; thus VATT-PEPSI-TESS acquires spectra of the brightest Sun-like stars (F, G, and K spectral types; the Sun is a G-type star) in the vicinity of the north ecliptic pole. Each target is observed twice, each exposure time is approximately 80 minutes.

The observations are carried out by on-site VATT operators, and PEPSI operators who work remotely from the AIP or from home. Our principal AIP collaborators are Klaus Strassmeier, Michael Weber, David Gruner, Ilya Ilyin, Matthias Steffen, Silva Jarvinen, Thomas Granzer, Sydney Barnes, Thorsten Carroll, Matthias Mallonn, and Daniel Sablowski.

Only rarely are PEPSI operators at the instrument in the LBT building; however, until the robotization of the VATT is completed, the VATT operator needs to be on site. The "default" VATT operator for this project has been Michael Franz, whose time is sponsored by the AIP. But over the years, VATT-PEPSI-TESS has also engaged University of Arizona students, mostly undergraduates, as VATT operators: Yuan Jea Hew, James Lilly, Kaylah McGowan, Chris Tulban, and Jeffrey Vickroy, as well as Kelly Waldvogel from Cornell.

Knowing the unknowable

Auguste Comte, the founder of French positivism, once wrote, "[With regard to stars] we would never know how to study by any means their chemical composition… In a word, our positive knowledge with respect to stars is necessarily limited solely to geometrical and mechanical phenomena…" (*Cours de Philosophie Positive*, II, 19. Paris 1835). He did not know that starlight carried the "fingerprints" of stellar composition. He did not know that starlight would be able to tell us about the star's temperature, gravity, spin, magnetic field, and even how violently the star's surface bubbles and boils. But indeed, Creation appears to be made in such a way as to allow us to understand it. Science is a long and slow journey; but whenever it has reached what looked like an insurmountable limit, every time, a new window has opened a new perspective, beckoning us along, delving ever deeper into the mystery which is this magnificent Universe of ours.

It is as if the Universe wanted to be known by human beings as if it wanted to be admired by us. We like to see this as a parallel to what biblical revelation tells us in the stories of the Patriarchs, of Israel, and especially of Jesus Christ. God, who wants to be known and worshiped by His people, is close to everyone of us.

— *David Brown and Paul Gabor*

Figure 8: Open hatches reveal the inner space around the spectrograph, which sits on a table of dimensions of 6x2 m. Top: On the left edge is the main collimator mirror seen, the blue-arm transfer collimator mirror is just close-by to the right. The graiting is in the black box to the very right of the picture. Middle: panoramic view of the red-arm side. Bottom: panoramic view of the blue side-arm side.

CHAPTER THREE

2021 A Year in Review

It has been a year of jubilees for many of the Vatican Observatory scientists as they learn to continue their research of the heavens even given the 'new normal' of a planet still in the clutches of a global pandemic.

Father Richard Boyle, SJ

Jean-Baptiste Kikwaya, Paul Gabor, and Carl Hergenrother joined me remotely on the night of October 6, as we took part in a global observing event of the Neptune occultation of a 14.9 magnitude star identified by the Gaia space telescope as: ID = 2633285513360476416 in the catalog GaiaER3. Dr. Damya Souami of the Paris Observatory Lucky Star project coordinated this worldwide campaign with the largest to smallest telescopes. We used the Galway Ultra-Fast Imager (GUFI) CCD camera on loan to us from Galway, Ireland.

Despite varying weather we had made test observations on October 3, and just prior to the onset of the occultation, to set the exposure time to be one half second of continuous streaming throughout the 2 hours of the occultation environment.

On the video monitor of GUFI we watched Neptune's 2.4 arc-second disk move over the star into immersion and later reveal it again in the emersion. Because the planet was relatively bright (7.5 magnitude) compared to the star, we had purchased an optical filter centered at the wavelength 0.89 nm where methane in Neptune's atmosphere absorbs solar radiation but would allow the star being occulted to show brighter to dimmer as it probes through the atmosphere of the planet.

At the same time the Large Binocular Telescope just 500 meters away (see photo), also at MGIO and virtually at the same footprint of the shadow of Neptune in the occultation, was probing the light in the near-infrared K-band.

The data processing of all observations made by the participating telescopes is being carried out by the Lucky Star center. It will take months to do a detailed analysis of the aspects and correlations seen in the occultation. The goal of this global observational campaign is to learn more about Neptune's atmosphere and environment including the partial rings, called "arcs".

This past year I made almost monthly observations at VATT in the Vilnius Photometric System of seven filters for galactic star clusters including Bright Rim Clouds in our collaboration with B-G Andersson and Archana Soami of NASA Ames Research Center. We provide them with the total extinction Av per star for which they have polarimetry to further the understanding of the astrophysics of the environment for star formation. This is part of an ongoing collaboration with Robert Janusz, SJ, and Vytautas Straizys, Algirdas Kazlauskas et al. of Vilnius University.

I also observed in the SDSS g', r', i' filters some select stars of the Gaia Alerts that may be showing micro-lensing effects in the Milky Way. This project is in collaboration with Marius Maskoliunas and Justas Zdanavicius of Vilnius University.

I also observed some nearby cool stars in the EDEN project of Daniel Apai, Steward Observatory, to search for exoplanets, using the red filter GG495. Such observing with the 4KCCD camera involves continuous exposures of a minute or two for several hours to detect signs indicative of planets in an analysis of the star's light curve.

My search for asteroids in collaboration with Kazimieras Cernis of Vilnius University also continues.

The frequent observing time I have at VATT allows me to test its operation, for example just after the re-installation of the primary and secondary mirrors after their re-aluminization in August, as well as telescope and camera software.

What's more, this year I also got to instruct Chad Trujillo and Colin Chandler of Northern Arizona University, each over 3 nights, so they could be certified to operate VATT and so pursue their research in objects of the solar system. And I welcomed Mark Trueblood to VATT, so he could familiarize himself with updated aspects of operating VATT, prior to the Lebofsky, Trueblood and Crawford observing runs for asteroid research.

But I give particular thanks this jubilee year, celebrating my endeavors over 60 years in the Society of Jesus and 40 with the Vatican Observatory.

Father David Brown, SJ

The year 2021, for as much as it was affected by the challenges of the Covid pandemic, began on a joyful note because of this year being the 30th anniversary of my entrance into the Society of Jesus, which graciously assigned me to the Vatican Observatory.

As was the case for most people in the country, the first few months were spent in lockdown, for me in Tucson, at the Arizona branch of the Vatican Observatory, home of VORG and of the Lennon/VATT telescope facility.

Even so, I was still able to go, under tight restrictions, to my office to do research. Most of this involved sifting through high-resolution spectra of stars obtained from the VATT-PEPSI-TESS observation runs of the past few years (see the description in chapter two for a more details).

The first few months (January - April) were spent developing the methodology by which the chemical abundances of the VATT-PEPSI-TESS survey stars would be obtained. Late April saw the beginning of the actual process of determining the chemical abundances of those same stars.

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With the pandemic abating somewhat during the late-Spring and the resumption of travel, May through mid-June were spent doing my home visit, retreat, officiating at weddings, and attending some ordinations.

Upon my return to Tucson, observations of the VATT-PEPSI-TESS survey stars for 2021 were already underway, with Paul Gabor and Michael Franz having been the onsite observers at the Lennon-VATT facility on Mt. Graham for the first few weeks. I continued the observations as the onsite observer during June – July, with Michael Franz returning mid-July to continue the observations.

I resumed my work in Tucson of extracting the chemical abundances from the PEPSI stellar spectra at VORG offices at Steward Observatory, before heading back to Rome mid-August.

First, however, I spent one week in at Fordham University New York. The purpose was to confer with Fr. John Cunningham, SJ, physicist and astronomer at Fordham, over how to process the data that we had obtained with an observing run at VATT, using the VATTSpec spectrograph, in early 2020 before the pandemic began.

The aim of the project is to use medium-resolution spectra, obtained with VATTSpec, of stars to determine their chemical abundances by different methods. We hope to publish the results sometime in 2022 or early 2023.

I spent August - October in Italy working at the Roman headquarters of the Vatican Observatory, continuing the work of the VATT-PEPSI collaboration. The time spent there was also an opportunity to come together with my brethren at the Observatory (both the Roman and Tucson astronomers in one location) in order to share the progress and results of that work in a seminar given at the Vatican Observatory on October 21, 2021.

In November, I returned to VORG in Tucson, where I continue with my work for the VATT-PEPSI collaboration. 2021 ended with a series of lectures in Denver, CO at Regis Jesuit High School summing up a year of settling into a 'new normal'.

Brother Guy Consolmagno, SJ

The year 2021 came in two parts. The first four months, through the end of April, were a continuation of life in Tucson under the Covid protocols begun in 2020, with no travel and a lot of interaction online.

Then, after receiving the second dose of the Covid vaccine in early March I was able to plan travel including finally getting back to Rome in early May, where I stayed until August. Fall was spent in the US giving talks and meeting with Vatican Observatory Foundation donors, and winter saw me back to Rome.

Much of this year has been occupied with activities concerning the Foundation. The months in Tucson also marked the final work on preparing the new web site for the Vatican Observatory Foundation (see chapter 1).

Meanwhile, I have continued my activities on the Science Advisory Board of the SETI Institute and chairing the Mars Task Group of the IAU Working Group on Planetary System Nomenclature. It has been a particular busy year for Mars, with names for more than 50 features discussed via more than three hundred emails (so far) this year.

My own scientific work has been sidetracked since Covid shut down the Boston College lab of our prime collaborator Fr. Cy Opeil SJ where meteorite physical properties are measured. One gratifying bit of science this year was not by me but from a team on the OSIRIS-REx mission at the University of Arizona led by Saverio Cambioni. This October, he and his team published a paper in *Nature* on the porous nature of the rocks that cover asteroid Bennu; two key elements of their analysis relied on work that has come out of our laboratory in Castel Gandolfo. They estimated the porosity of rocks observed from their temperatures as seen from orbit around Bennu by applying the relationship between meteorite porosity and thermal conductivity that we had published in 2018. And they proposed that extensive cracking in those rocks arose from the thermal flexing systematics of CM meteorites that we published last year. This is a good reminder that one can never predict ahead of time just how important our laboratory data can be to approaching a wide range of planetary science questions.

Perhaps the most important milestone in 2021 for me was the publication of the book that Ileana Chinnici and I edited, *Angelo Secchi and Nineteenth Century Science*. Several of the chapters were submitted to us in Italian, and many others by authors whose first language is not English. My work on it turned out to be a labor of love, as I learned so much about Secchi and his scientific work that even after the events of his bicentennial year of 2018 still surprised and amazed me. To cite one example, Secchi advanced not only scientific knowledge but how we go about getting that knowledge. To quote from my introduction:

The natural philosopher of 1801—toiling before even the word scientist had been coined—would not recognize the life of a scientist of 1860. By contrast, Secchi's day to day activities are not all that unrecognizable to a scientist of today. From his time forward, science would be the enterprise of collaborations tied together by modern communication technology; the collection of data would depend more and more on complex instruments of a sort that would require a team of supporting engineers; and its support would be closely tied to government funding of both universities and national observatories.

This year I was also able to write two booklets on science and spirituality. The first to appear, *Sole*, was commissioned by the Italian Franciscans as a part of a series where many authors were invited to reflect on a particular phrase from the poem of St. Francis of Assisi, *Laudato Si'*. I was given the stanza on the "sun, moon, and stars" and so I reflected on my life of an astronomer. They shortened the title to just "Sun" (Sole, in Italian) even though I never actually talked about the Sun itself! Instead, I described a dozen episodes in my life where my study of the stars and planets led to me a deeper appreciation of God.

The second book likewise is a part of a series, this one in English, under the general rubric of "My Theology." It was published by the British religious publishing house of Darton, Longman and Todd. Their idea was to collect a wide range of Christian thinkers, like Alister McGrath and Ann Loades, to reflect on how each of us has come to know God; I was invited to write on the theme of *Finding God in the Universe*. In this book, I drew parallels about how a community of scientists can come ever closer to understanding the universe and how a community of believers can advance each other's pilgrimage toward a deeper love of God.

Most recently, I was invited by the Jesuitical podcast affiliated with *America* Magazine to reflect on science and science skepticism in the light of public reaction for and against the Covid vaccine. At their invitation I also prepared a short written article which appeared on the America web site, concerning the problems behind the popular slogan to "Follow the Science." That has since been expanded into a longer article which should appear in *La Civiltà Cattolica* sometime early next year.

Father Christopher Corbally, SJ

In my account of 2020's activities I didn't reveal the name of the 'mystery object' into whose investigating team I had been invited some four years ago. This object had been discovered by the Global Network of Astronomical Telescopes (GNAT), thanks to the images taken at the Goodricke-Pigott Observatory (GPO) near Tucson by Roy Tucker. The object's brightness has varied over 20 years of observation with a mean period of 6.65 days, though occasionally it has had extremely high energy outbursts.

The story continued this year both with sadness and happiness. The sadness was over Roy, the person who kindly arranged last year that an asteroid (119248) he discovered at his GPO was named Corbally. Now Roy had been battling cancer for a while, and sadly he passed away on 5 March 2021. But this was not before he knew that a paper about the mystery object had been submitted to a leading journal and was well on its way to acceptance, under the guidance of Roy's close friend, Eric Craine.

Our anticipated happiness over this tribute to Roy was fulfilled through its publication by *The Astrophysical Journal Supplement Series* in September, with Roy A. Tucker as its principal author. The paper was called MG1-688432: A Peculiar Variable System. We could now reveal the name of the object, claim its discovery, and put forward our speculations as to its nature.

Spectroscopy over two six-night runs with VATT had confirmed suspicion that MG1-688432 is not a single object. Rather it is made up of two components, a primary and a secondary orbiting each other. The primary is a cool subgiant star, but shows a far from normal, and variable spectrum. We cannot see its companion either visibly or in the spectrum, so it must be much fainter. However, the 6.65 day variations in the primary's velocity, as revealed by wavelength shifts of features in its spectrum, show that the companion exists. And now the speculation starts as to what is causing the sometimes extreme variations in brightness.

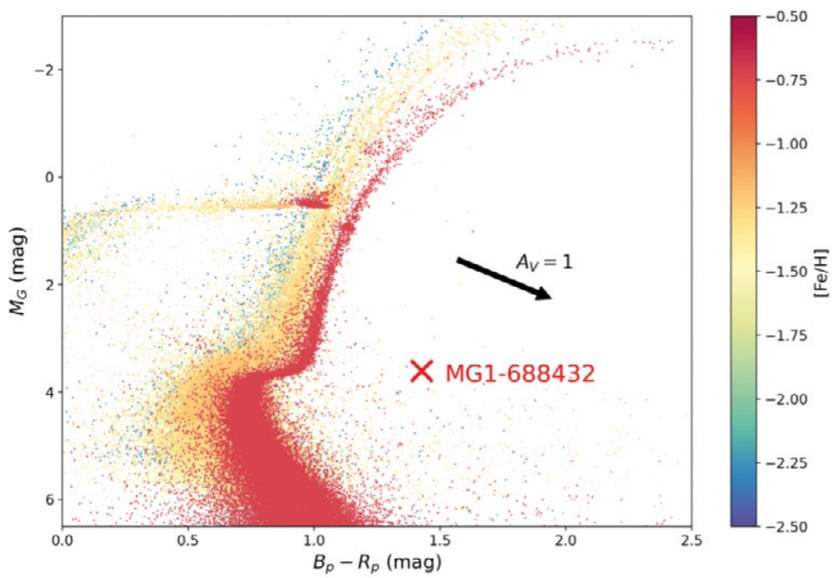
The diagram below is a standard way of relating a star to others by plotting its color (B_p-R_p), indicating its surface temperature with cooler to the right, against its brightness (M_G). The red cross in the figure shows how MG1-688432's primary lies with respect to star cluster sequences having various iron abundances [Fe/H]. It is way outside the normal position for subgiant stars of its galactic population.

Maybe dust clouds internal to the system have reddened the primary (see the A_v arrow for the effect of a modest amount of interstellar dust), but the effect of dust is not seen in its spectrum. An exciting possibility is that an earlier transfer of mass from the unseen secondary to the primary has given the primary its out-of-position characteristic as a "red straggler".

However, the intense outbursts, perhaps from the now compact secondary, still need an explanation. For that we need observations from larger telescopes and in new wavelength regions, and this discovery paper will help attract suitable collaborators.

With the Astronomy Department at the University of Arizona reaching a 'new normal' occupation, now that all staff and faculty are vaccinated against Covid-19, work in our office area has become pleasanter. But some good aspects of the pandemic have persisted, like Zoom sessions able to connect one easily with international collaborators. I have continued meeting every fortnight, when possible, with the Spectroscopy Discussion Group made up of professional astronomers and skilled amateurs. They were helpful in advising me on revisions to the section in the *Observer's Handbook on Spectroscopy of Stars*. After all, they are the experts.

Interdisciplinary research has continued to bring me delight, with written papers and chapters to show this year, thanks to a number of collaborators, particularly Margaret Boone Rappaport (Human Sentience Project). At the turn of the year, we submitted a chapter on how we humans are likely to find ourselves different through living on the Moon, not just during year-long expeditions but permanently. This took imagination coupled with science, technology, art, recreation, culture, and even religion. It has become the last chapter in a book co-edited by Rappaport and Szocik entitled *The Human Factor in the Settlement of the Moon, an Interdisciplinary Approach*.



The position of MG1-688432 is shown in the Gaia color magnitude diagram (M_G vs $B_p - R_p$), as well as the cluster sequences of Gaia Collaboration.

Father Richard D'Souza, SJ

After a year of settling down, life in Albano has finally picked up pace. On the academic front, my collaborators and I made a lot of progress on completing some long-overdue projects regarding the dwarf satellite galaxy populations of Milky Way-mass galaxies.

Earlier this year, we published a theoretical paper demonstrating how when Milky Way-mass galaxies accrete a large satellite galaxy like the Large Magellanic Clouds (LMC) during their lifetime, they also accrete a bunch of smaller satellites.

In fact, we demonstrated that the accretion times of the surviving satellites of the Milky Way and the Andromeda galaxy (M31) are broadly coincident with the accretion time of their most massive progenitors or satellites, i.e., the LMC and Gaia-Enceladus (an ancient merger ~ 10 Gyr ago) in the case of the Milky Way, and M32p (about ~6 Gyr ago) in the case of M31.

The picture that is emerging is that galaxies like the LMC not only contribute their own satellites, but they also gravitationally focus surrounding satellites onto the Milky Way. On the observational front, we submitted a paper lead by Adam Smercina showing that for nearby Milky Way-mass galaxies, the number of classical satellites correlates tightly with the mass of the largest accretion event.

Although this reinforces the view that these present and previously destroyed large satellite galaxies are key to understanding the present-day satellite populations, we still have a long way to go before we have a comprehensive theory explaining the satellite populations of Milky Way-like galaxies. Future data from upcoming facilities like Vera Rubin Observatory, James Webb and Nancy Grace Roman space telescopes will help our future in the development of a comprehensive theory.

On the other hand it nice to see that my previous work on stellar haloes, made up from the debris of these large, massive satellites and the present-day satellites, informing my present work on satellite populations.

Along with my colleague Antonella Monachesi at the University of La Serena, we started working on analyzing some data from the Multi Unit Spectroscopic Explorer (MUSE) on the 8-m Very Large Telescope (VLT) in Chile.

With this project, we hope to determine the velocity dispersion of resolved stars on the outskirts of the galaxy NGC 4945 which is nearly 3.6 Mpc away. This will the first dynamical measurement of the stellar halo of a galaxy outside the Local Group. While it is a difficult and challenging project, we are having much fun learning along the way.

My knowledge of Italian is also slowly improving. After Covid restrictions eased in Italy in May 2020, I began helping pastorally at the local parish. Every Sunday, I celebrate a Mass in Italian at the Cathedral of Albano across the square from the Specola. While it is a lot of work writing a homily in Italian, I feel sorry for the Italians who as a captive audience are forced to listen to my mistakes and poor pronunciations!

This year I gave a series of popular online talks entitled "The 5 Big ideas that changed our understanding of the Universe in the Last Century" to a group of around 150 persons in my home province of Goa, India.

Finally, in Summer of this year, I spent two months in Goa with my parents and helping them out. I even managed to get some work done remotely from India.

Father Pavel Gabor, SJ

My last-year's Annual Report entry concluded, "…[I am] looking forward to the coming months and the end of the pandemic." If anything, 2021 was even more quirky than 2020. The strangest part was an unplanned 3-month stay at Castel Gandolfo.

My original idea was to avoid traveling to Europe this summer, but it so happened that I was elected to the Provincial Congregation of the Province of Bohemia, held at Velehrad Aug 30 – Sep 3. Elected members must participate.

Unfortunately, I received the travel documents needed for my return to Arizona much later than I had anticipated. The US State Department officially recognized the Observatory's seat in Arizona as a Miscellaneous Foreign Government Office already at the end of August but it took three additional months for the new legal reality's consequences to percolate through the system.

There were many positive developments in the 2021 mix. The single most important item on the VATT front was the realuminization of the mirrors (see chapter 5) which turned out to be very successful, improving the telescope's performance in two significant ways: greater reflectivity and less scattering bringing more starlight to the telescope's detectors, and better seeing due to reduced turbulent air flow in the central "Cassegrain" hole of the primary mirror thanks to a new gasket.

Two of my major research projects reached auspicious points in their timelines, the respective teams preparing to wrap up the observing part of our programs. The EDEN Transit Survey evaluated how many stars remained to be observed and found that we were approaching our intended volume-completeness covering nearly all of our targets of interest within our given volume of space, viz., within 15 parsecs (50 light years).

Similarly, the VATT-PEPSI-TESS (see chapter 2) ultra-high-resolution spectroscopic survey completed data acquisition of 90% of the 311 intended targets. We should have no trouble completing both observing programs in 2022.

Teaching "my" history and philosophy of astronomy class in an online format (due to Covid19) pushed me decisively towards an approach with which I had toyed with for some time. It is called flipped classroom, i.e., your students do "homework" in the classroom and "classwork" at home.

I recorded my presentation of the material in advance. These videos were 15-25 minutes long. Each student watched them at his or her convenience before the corresponding online class session.

The students were motivated to do so in a timely fashion by a quiz integrated into the video. Every few minutes, the playback would pause and not allow the student go any further until he or she answered some quiz questions. The question would be of the fill-in-the-blanks kind and the text would be, more or less, a transcript of what was just said in the video.

Simply reading the question meant that the student went through the material, and the words he or she had to type in the blanks were important names or terms. The students would thus familiarize themselves with the terms through a sequence of simple hearing, reading, and writing activities.

The virtual class sessions were devoted to discussion of the material and other interactive activities. I found that a good way to launch a discussion was a quiz which the students worked out in break-out groups of 4 or 5 individuals.

Some of the questions concerned fundamental astronomical concepts, e.g., types of apparent motion of a sun in the sky of an alien planetary body, the apparent motions in the sky of your planet of moon of your own planet and of other planets of the same system.

Another type of activity in our live online sessions was writing summaries of texts together and/or in break-out groups, finding bibliographical references for a given problem, etc. Students would write short reports and submit them individually.

On the whole, I found that the students engaged well. Unfortunately, towards the end of the semester, general demotivation and lethargy grew due to the students' prolonged social isolation.

There are many things I am hoping 2022 brings. A contract for the completion of VATT's robotization, the postponed General Assembly of the International Astronomical Union, new research projects and new collaborations… All this would be great, but I would settle for just a moderate abatement of the current levels of quirkiness.

Father Gabriele Gionti, SJ

2021 was again characterized by the long shadow cast by the Covid pandemic over all of my scientific and pastoral activities.

Most of the latter part of 2020 was spent proofing an article on the canonical analysis of Brans-Dicke theory published in *Physical Review D* (PRD). I was still astonished that a referee said the article did not fit all the standards of *Physical Review Letters* and yet it was immediately accepted for PRD.

We also finally and definitively fixed an age-old problem with the Specola internet connection, allowing me to give a series of online talks. In the past, the connection was not strong enough for video, forcing us to take part in online activities without video. Thanks to Davide Giordano at the Vatican internet office this problem was resolved, which meant I could deliver a popular Quantum Gravity talk to the students and professors of the Physic Department of the Pontifical University Javeriana in Bogotà, Colombia.

January began with annual spiritual exercises from which I drew renewed energy for a project on communicating the basic ideas behind quantum mechanics for people with a background in theology. I asked many people to edit my paper, but I quickly realized it was not as readable as I had thought for people with seminary formation. What this exercise did teach me however, was that I need to improve my skills in communicating science to the general public.

Parallel to this project in collaboration with Matteo Galaverni, I began work on a longer article on the canonical analysis of a specific case of Brans-Dicke theory ($\omega=-3/2$) which has some features suitable for some cosmological applications (including some "quantum gravity phenomenology").

We also finished and published an article on Chiral anomaly and photon helicity non conservation. The latter studies a "quantum" effect according to which the merging of two

neutron stars also generates an electromagnetic effect besides a detection of a gravitational wave. This effect really exists but, being of quantum nature, is very small.

Spring and summer were periods of hectic activity in online talks and in person conferences, while I continued my pastoral work at the local church of "Santa Maria Assunta" in Ariccia, and at the local prison in Velletri.

My prison work is particularly rewarding. I was delighted to have helped coach an inmate there for his exams in statistics and was thrilled at the enthusiastic response to a class I offered in basic astronomy.

After the summer vacation and for the first time since the pandemic started, I personally attended the meeting of the Italian Society of General Relativity and Gravitational Physics in Urbino. This trip clashed with the ordination of the new bishop of Albano Laziale, Mons. Vincenzo Viva, but a little extra travel allowed me to attend both. The

cherry on the cake, I even made it to my hometown Capua for a dinner with my high school friends.

My travels this year took me to Amelia for a panel on the "Laudato Si" organized by the Conventual Minor Franciscan that run a planetarium there. Later, in the Autumn, I gave a public talk on the "Laudato Si" and Science-Theology with the help of Francesco Cecchetti and Antonio Scala (CNR Rome) to university student gathered in Assisi on the occasion of the 41th young adults gathering organized by Conventual Franciscans.

On October 25th, we hosted at the Specola a Seminar by Claudio Gatti and Danilo Babusci (Frascati National Laboratories of the Italian Institute for Nuclear Physics: LNF-INFN) on "Axion in Dark Matter and Analogue Gravity." Paolo Beltrame SJ, Matteo Galaverni and I are planning to establish a research project with them on these topics.

Father Robert Janusz, SJ

This year was a busy one for our photometry group. The pandemic gave us the time we needed to obtain observation data sets to reduce in various ways.

We have developed data reduction techniques that allow us to develop a tie-in method for fields of view where there are no standards for calibrations. This method uses a sequential observation of known (A) and unknown (B) star fields in a series of A-B-A-B-A, so we can check that the transparency of the sky and constancy of air mass is similar for A and B.

A second problem is an optimization of classification within the ranges for zero-point errors of the standard stars. The color parameters we always take from a quick comparison with data of M67/M29 calibration clusters can serve as flat field corrections for us as well.

The new 64 CPU server is excellent for our work, especially when parallel computing is used. This is not such an easy task, because we still use the IRAF software which was written for a one core "cl" user interface. Thus to use parallel optimization of our results has presented us with a very challenging project. It feels like we are just at the beginning; I am as excited as a kid on the first day of class at a fantastic school.

These calculations reveal the beauty of numbers and relations between them, where the hidden information of star clusters and their evolution waits to be revealed. One can contemplate the Lord's creation through the language of mathematics, and this is a privilege afforded every day to those of us who work in real science.

This Autumn, I also gave my first presentation of how we study the stars on the VATT: "The essential ideas of the Vilnius Photometric System" to our scientific community in Castel Gandolfo.

Father Jean-Baptiste Kikwaya-Eluo, SJ

Rebecca Feldman, an assistant professor from the University of British Colombia, in Canada, asked me to give a talk to her students. There were about 70 of them. Rebecca and I defended our PhD thesis one day apart from one another in 2011. The talk I gave on November 19th, 2021, had the title "Physical characterization of fast rotator Neos."

My goal in this talk was show to the students from end to end the different steps I go through while I do science (astronomy). I went from gathering data using the telescope to displaying the results from which connections to previous knowledge could be established.

"Is it not so difficult to do science, then?", they asked me. And my answer was: "No, it is not! There are some values embedded in the process of doing science that are not obvious, but this is all that is required to be a scientist: discipline, honesty, and above all humility". Indeed, we may admire scientists more for their so-called accomplishment than from what made it possible. And as scientist, Catholic, religious, priest, and working for the Roman Catholic church, I try not only to lead people to my "work", but also to open the door to all these values without which my "work" would not stand.

In the end, we must answer this question: what is more important and impressive: the river that turns the sea salt water into fresh water, the green trees producing fruits monthly on both banks of the river, or the sanctuary from which the river originates? (Ez: 47,1-2; 8-9; 12: Dedication of the Lateran Basilica in Rome).

On March 4, 2021, I gave a talk to Canadian high school students during their OPECO (Office Provincial de l'Education de la foi Catholique) annual conference 2021. The title of the talk was "Science and Faith: Defense or conversation?" I tried in this talk to answer the question: could science open us to faith? Is there a direct link between science and faith? Could a scientist be led to faith just from being scientist? The answer is: no!

But if science is conceived as life experience, then it comprises more than just the activity of doing of science. It becomes a living place, building bridges between it and all the other domains of life; and then faith can also become evident in the process.

Besides my work on Near Earth Objects, I also work on meteoroids. In Tucson, in collaboration with NASA I run a network of three all-sky cameras, one installed at Kitt Peak, one on Mount Lemmon, and one on Mt Hopkins.

The project has two goals. The first goal is to monitor bright meteors (fireballs of magnitude brighter than 3) in the region. Here we compute the trajectory of the meteoroid to get its beginning and ending heights, its velocity, its deceleration, its orbital elements to determine its origin (asteroidal or cometary). We also produce its light curve to get its photometric mass. The second goal is to organize a field project with high school students to recover meteorites, in the case that some fireballs are big enough to produce them.

During the pandemic, I worked on coupling the fireball network with another one that captures only faint meteors (more than 7 magnitude). This network of three small field of view cameras will join the New Mexico meteor network.

At Castel Gandolfo, in Europe, I joined FRIPON, a network of all-sky cameras that captures only those fireballs capable of producing meteorites. The Vatican observatory now has an all-sky camera installed on its roof (see chapter 5).

Father Giuseppe Koch, SJ

In a year marked by Covid, the presence of guests in the library has fallen to practically zero. But during this time I have been able to continue the work of updating our digital catalog.

This year, most of the volumes published under various titles relating to the activities and reports of the Roman College have been added, including the volumes of the *Meteorological Bulletin* edited by Fr. Angelo Secchi.

In addition, we have added the volumes published under the title of *Publications of the Vatican Observatory* going back to the beginning of the Specola. These are all the texts published between 1803 and 1967; note that some of them were published during the suppression of the Society of Jesus.

But along with that, I would like to note that my activity at the Specola is not restricted to my presence in the library for the normal work required there. I also have the pleasure of engaging in pastoral activities with groups of adults in Rome: sessions of deepening our knowledge of Scripture, followed by the celebration of the Holy Mass, and ending with a convivial social gathering. We hold these events in the Sala Clavius, rather than the house Chapel, since it allows for more space for the distancing necessary during these times.

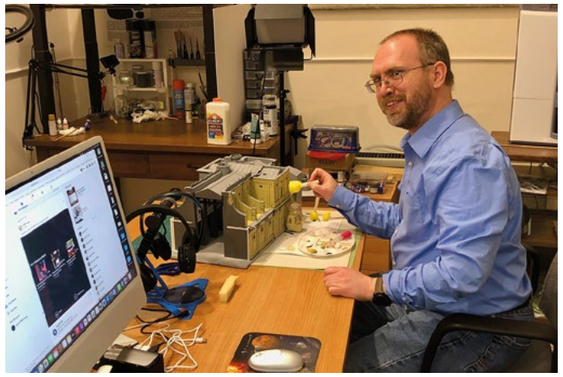
Brother Robert Macke, SJ

This has been kind of a slow year for my research, but not unproductive. First, I am pounding away at a paper with collaborators Consolmagno, Opeil, and Britt about thermal properties of lunar materials. We have measured thermal properties at cryogenic temperatures which can help us understand how lunar surface materials behave in the very cold permanently shadowed regions at the lunar poles. We have presented our work at several conferences this year, and the paper should hopefully be in process soon. Second, I have continued a collaboration with the Desert Fireball Network in Australia. Often, as part of characterizing meteorite specimens that they have tracked as fireballs and subsequently collected, they will send the meteorite to me for density and porosity determination. I have measured a few of their specimens this year. I also continue to measure density and porosity for other meteorites that people are studying for various reasons.

Most excitingly, this year has been important for the two (!) space missions that I am involved in. First, the Lucy mission launched on October 16. I was unable to travel to Florida to watch it first-hand, but I did write a Sacred Space Astronomy blog post reflecting on the event. This mission will visit several Trojan asteroids between 2027 and 2033. Second, I have joined the science team for the OSIRIS-REx mission that just last year collected material from the asteroid Bennu.

As a member of the Sample Physical and Thermal Analysis Working Group (SPTAWG), I will help measure density and porosity of the specimens after they return to Earth in 2023. Along with working group lead Andrew Ryan,

From left: Gionti, Macke, and Galaverni before the statue of Eusebio Kino in Segno, Italy.



I am advising a team of senior engineering students at the University of Arizona to design a new pycnometer to be placed in the glove box where the specimens will be analysed.

In my free time, I enjoy making small-scale models and dioramas, and this year I have taken up this hobby with gusto. I created several interesting pieces. These include some Star Wars dioramas, an art piece I call Rupnik's Cube, and an Iron Man inspired piece involving the MIT class ring, commonly known as the Brass Rat.

The piece that has occupied most of my free time, however, is a model of Fr. Angelo Secchi's observatory that sat atop the Church of St. Ignatius in Rome. For those unfamiliar with the scientist, Secchi was director of the Observatory of the Roman College who built a new facility atop the church in the mid-19th century. From there, he carried out pioneering research in astrophysics, stellar spectroscopy, solar physics, and terrestrial magnetism. When I have completed this masterpiece, it will be displayed in our visitor center where we house the Carte du Ciel and Schmidt telescopes.

One other item of interest is a little trip I took with Fr. Gabriele Gionti and Fr. Matteo Galaverni. While we were vacationing in the Dolomites, we made a special visit to the town of Segno, where Eusebio Kino (originally Chini) was born. This year Tucson celebrated the 30th anniversary of the gift of the statue of Kino to the town, so we naturally had to visit.

This year, I also received an invitation from Fr. General Arturo Sosa SJ to pronounce final vows as a Jesuit brother. I will be making the vows along with at least two other Jesuits in February of 2022.

Father Paul Mueller, SJ

As the COVID situation eased somewhat in Italy during 2021 – or perhaps I should say as the COVID situation became the "new normal" – it became possible once again for us to receive small groups of visitors at the Vatican Observatory. We had seen no visitors at all during the final 10 months of 2020!

At the start of 2021 it was my pleasure to host a visit to the Observatory for USA Ambassador to the Holy See Callista Gingrich and her husband Newt Gingrich – who seems to have quite an interest in space-related issues, and who had a long session chatting with Br. Bob Macke about meteorites!

Later in the year I helped host visits from French ambassador to the Holy See Élisabeth Beton-Delègue, Dutch Ambassdor to the Holy See Caroline Weijers, and Australian ambassador to the Holy See Melissa Hitchman. Over the years I have found it intriguing and consoling to meet and chat with various ambassadors to the Holy See: each one seems to have his or her unique take on how to combine the demands of diplomacy and faith!

In March we welcomed Vatican Museums Director Barbara Jatta. She brought with her to the Observatory a rather special work of art that had been carefully and lovingly repaired and restored by the team of experts at the Museums: a model of the solar system made entirely of stones and jewels, which now is mounted on the wall in the "visitor center" located under the Observatory's telescopes in the papal gardens at Castel Gandolfo. On that same visit Director Jatta arranged for the visitor center to receive high-resolution copies of Donato Creti's *Astronomical Observations*, a series of eight 18th century paintings depicting the Sun, Moon, and planets.

Apart from receiving these and other visits, most of my time was taken up with routine-but-necessary work of administration in my roles as vice director of the Observatory at Castel Gandolfo and as religious superior of the Jesuit community of the Observatory. At one level my work as vice director and superior has been simplified by COVID – there are fewer activities and events to be managed! At another level my work has become more difficult and complex, as I have deal with the long-term stresses and strains that COVID is imposing on everyone, including the Jesuits and lay employees of the Observatory.

But I did manage to give some public talks and presentations during the past year. Some examples include a Zoom talk on science-faith issues to a group of college students organized by a consortium of campus ministries, and an online lecture for the Asian chapter of the Vatican Museums Patrons of the Arts, "The Vatican Observatory: 400+ Years of Science and Faith". Also I gave the paper "Bellarmino, nella storia e nella scienza del suo tempo" at the conference conference *Bellarmino e I Gesuiti a Montepulciano*. This conference was organized at Montepulciano, the birth-place of St. Robert Bellarmine SJ at Montepulciano, on the occasion of the 400th anniversary of his death.

Father Alessandro Omizzolo

We all thought that 2021 would bring some normality back to our life and scientific work but it was not to be. We had adapted to the fact that we would no longer have meetings in person, renewing contacts, being able to share the results of our research, to exchange opinions and evaluations, to collect criticism of our mistakes face to face. Instead …. another year of video conferences on the Zoom platform, another year of online meetings, another year of having to give up seeing our colleagues … and once again we made a virtue out of necessity.

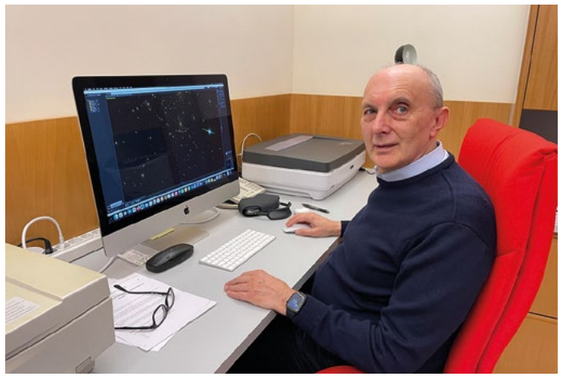
With the GASP group (GAs Stripping Phenomena in galaxies), we continued to work on our own, comparing our work on a fortnightly basis. In the absence of the possibility of going directly to a telescope to observe and obtain the data we need, our work consisted substantially in squeezing every last drop out of the data in our possession that had not been studied up to this point.

We focused on the analysis of some galaxies particularly interesting for the study of phenomena such as "jellyfish" and "ram pressure stripping", trying to capture any relationships between the physical processes involved in these phenomena: How is ram pressure stripping related to the evolution of galaxies in galaxy clusters? And again, how does ram-pressure stripping affect star formation in the material that galaxies lose as a result of their motion in the cluster? How does the presence, at the centre of the affected galaxy, of an AGN condition the star formation phenomenon in the tails of the ripped galaxy? How does the position of galaxies inside the cluster affect the morphology of jellyfish galaxies?

These are the topics we have been and are working on, as well as recapping the first Jellyfish galaxy catalog produced in 2016 to refine the classification of them in light of our results so far.

Even the activity of educational outreach was abruptly interrupted and only in recent months something timidly started again (in my case a conference in Rovigo on vacuum in the cosmos).

This lack or scarcity of external activity has allowed me to concentrate on the work of scanning the plates, which is nearing completion: the archive of plates obtained with the double astrograph has been completely digitized and the files are being sent to Germany where, together with the plates of the Schmidt telescope and the Carte du Ciel, they will form the digital deposit of the photographic archive of the Vatican Observatory that will become accessible via web to researchers all over the world.



The scanning of the plates of the Double Astrograph, plates that are large in size and of a wide field, has been a source of surprise, wonder, and reflection. Surprise in seeing how even in the last century the Specola astronomers were already observing nebulae, galaxies, planets and asteroids from the Castel Gandolfo site without the fear of light pollution issues (at least until the 1960s), obtaining results of great scientific value (for example, the study of the "Vatican Variables").

I am amazed at the quality of the images and spectra obtained, and at the amount of work involved in manually measuring the plates (positions, magnitudes, wavelengths): all this work is now done automatically by software dedicated to this type of research. (I am always impressed by the image of the Sisters of the Child Mary measuring the plates of the Carte du Ciel, something that today is done in infinitely shorter time and with greater precision).

Comparing the plates obtained at the beginning of the century with those obtained at the time of the closure of the telescopes at Castel Gandolfo (when the work of observation was transferred to Arizona at the end of the 80's) reveals the growth of light pollution, of which we are all victims. This not only robs astronomers of their sky but it also deprives ordinary people the ability to raise their eyes to the sky and say "The heavens tell the glory of God".

This has kept me busy during this year, along with a continuous reflection on the relationship between scientific research, its results, and comparison with faith.

In fact, I edited the publication of the latest work of Msgr. Antonio Mattiazzo on this subject and it will be released in bookstores next Easter as an aid for educators called to address the questions and doubts that scientific discoveries raise in young people today.

ADJUNCT SCHOLARS

Aldo Altamore

My work at the Vatican Observatory focuses on the history of astronomy, particularly the development of astrophysics in the Roman area, from the Specola's establishment in the mid-19th century to present time.

In this framework, as member of the National Committee founded by the Italian Ministry of Cultural Heritage, I was involved in the activities for the second centenary of the birth of Jesuit astronomer Angelo Secchi (1818-1878), who is considered the father of stellar astrophysics. The celebrations ended in October 2021.

I was also involved, as an expert, in the restoration of the Collegio Romano Observatory which is promoted by *Soprintendenza Speciale di Roma - Archeologia Belle Arti e Paesaggio.*

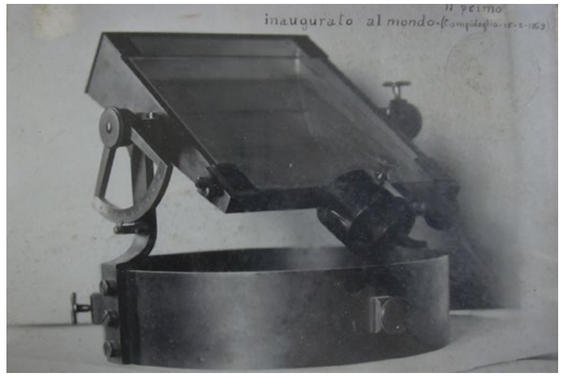
Within the limits imposed by the pandemic, I took also part in the general internal discussions on communicating science, as part of the Vatican Observatory's projects in the field of outreach and education.

In collaboration with the Rome Astronomical Observatory, I also started activities in view of the upcoming bicentenary of the birth of Lorenzo Respighi (1824-1889), director of Campidoglio Astronomical Observatory during the pontificate of Pius IX. Respighi was the inventor of objective prism, which allows the simultaneous collection

of thousands of spectra. The objective prism technique is today used in many observatories. The Specola historical collection of instruments includes some objective prisms which were used at the Vatican Schmidt Telescope until the mid 1980s.

In collaboration with Roma Tre University, I participated to the multicultural project "Astronomy for Development" addressed to schools with a considerable presence of immigrant pupils. In my everyday life, in addition to family commitments, I am an active member of my parish community of San Fulgenzio in Rome, as a lay minister of the Word and the Eucharist.

Secchi's prism.



Respighi's prism.

Father Louis Caruana, SJ

Philosophers like me often work on conceptual issues related to cosmology. My attention this year, however, was mainly on two other areas of current interest regarding faith and science: philosophical ecology, and the consequences of what is popularly called artificial intelligence.

Towards the end of December 2020, I was ending my research leave at Fordham University, New York. The lockdown conditions curtailed my interaction with faculty, but my stay was nevertheless productive, especially as regards work on some key ecological concepts like life and environment.

I critically examined the consequences of the fact that all lifeforms depend on other lifeforms, and how the entire biosphere could, in a sense, be considered one single unit of life. The resulting paper will be published in a collection of interdisciplinary studies, forthcoming towards the end of 2022, focusing on the implications of the papal encyclical *Laudato Si'*.

Further work in this area allowed me to embark on a book-length study of the philosophical and theological questions related to this area, with special reference to the work of St. Thomas Aquinas.

On February 22, at the Gregorian University in Rome, I presented a draft of this monograph's first chapter before the Philosophy Faculty and was encouraged to proceed with the project. I have now completed three of the six projected chapters and am hoping to complete the entire manuscript by February 2023.

Related to this research area, I continue to collaborate with the Laudato Si' Research Institute, based at Campion Hall, Oxford, principally by being a member of their advisory board. Now something about artificial intelligence.

The previous year, I had published a paper countering the idea that legal personality could be attributed to so-called intelligent machines. This year, in continuity with that work, I explored another dimension, namely the impact of such intelligent machines on employment—how they will make, or are already making, many workers redundant. The dynamics of this machine-takeover is mainly a matter of economics, but the effect it could have on self-understanding, in other words on the question of who we really are and who we should aspire to be, is a matter of philosophy. My research is still ongoing, but I have already had the opportunity of presenting some of my results during a conference organized by the Institute of Psychology at the Gregorian University.

As I see things, work in this area will remain significant for many years to come because it represents a relatively new area of fruitful dialogue between faith and science.

Ileana Chinnici

From March 2020 to September 2021, I was working from home online and this was, unexpectedly, very tiring! It was difficult to "disconnect" myself from working and to separate it from my private life. It was so stressful that it caused some health problems for me, as for many other people, I suspect!

So mid-October I returned to work at the Observatory, and this has given me the opportunity to be with my colleagues, to see and speak to them, to have more regular work schedule, and so on. My health has greatly benefitted from this new situation!

Early October, I spent about 10 days at the Specola, in order to work on the Denza-Secchi correspondence. It was a fruitful period of work for me because, while fully observing the Covid restrictions, I could participate in daily Mass with the Jesuit community and have a daily coffee-break with all the staff in the morning. It was a joy to see many of them, after such a long time. Before coming back to Palermo, I was invited to give a short seminar about my current research work.

It was also good to start traveling again. In July I was invited to participate in a meeting on "Science and Peace", held in Teramo. Normality seems to be gradually returning, even if prudence is still necessary.

2021 is also the last year of activity of the National Committee for the Bicentenary of the Birth of Angelo Secchi: I am concluding my service, with a rather satisfactory report. I am particularly happy to have published a book on Secchi with Guy Consolmagno. Now I am preparing the publication of Secchi's diaries – and this should be my last work on Secchi under my responsibility, even if some collaborations continue.

Michelle Francl-Donnay

The pandemic continued to keep me close to home this year but I enjoyed many virtual visits with colleagues and institutions far and wide. I particularly enjoyed giving a presentation on science as prayer for a group of MIT alums, including two members of the Specola.

My research group has shifted its focus to exploring metrics for characterizing the tightness of molecular knots, a problem of particular interest to biochemists. My four research students and I have enjoyed learning more topology for this project over the last 6 months.

I continue to write at the interface between science, culture and policy, co-authoring a piece on diversity in chemistry with a former student, and musing on the connections between science and poetry for an essay in *Nature Chemistry*.

I was pleased to contribute this year to two catechetical projects for Loyola Press. I recorded a piece for a forthcoming animated video for their religious education division on being a scientist of faith, and did an interview for an episode on science and faith for their new podcast series, *Carpool Catechesis*.

In February I did a virtual talk-back with the audience and the author of a play, *Steal Her Bones*, that was being performed at a local Philadelphia theater. The plot revolved around evolution, science, faith, and the afterlife; which sparked lively give and take. Later in the spring I participated in a conversation with physicist Marcelo Gleiser on his recent book *The Simple Beauty of the Unexpected: A Natural Philosopher's Quest for Trout and the Meaning of Everything* for the Magi Project through the Collegium Institute at the University of Pennsylvania.

In the early summer I completed the work on a short book on prayer, designed to be used as a guide for small faith sharing groups, or for parish retreats, which has recently been published by Liturgical Press. I continue to occasionally contribute essays and short meditations on the daily readings to *Give Us This Day*.

I'm back to teaching in person, both in the lecture halls and the laboratory; it's a grace and joy to be in the same literal space with my students. I was delighted to see Guy CONSOLMAGNO "in 3D" as he passed through Philadelphia between Florida and Rome in October. And finally, after years of collecting baseball cards, I finally have a card of my own, as part of the #WomenInChem series of trading cards designed by Compound Interest (see chapter 6).

Father José Funes, SJ

As a member of the International Astronomical Union, I recently received a communication from its Secretariat which pointed out that this last period has been marked by the extraordinary and tragic Covid-19 pandemic events and regional conflicts which have impacted all colleagues and their loved ones around the world. The communication continued to encourage the use of the power of the cosmic perspective now more than ever, starting from the famous Pale Blue Dot image as Carl Sagan described planet Earth.

Living in this global perspective, I have continued to do research and teach with all the challenges that the pandemic has brought with it.

The subject of the extraterrestrial intelligence (ETI) is so broad that it requires diversifying the multidisciplinary approach of our project OTHER (*Otros mundos, Tierra, Humanidad, and Espacio Remoto*), a multidisciplinary think tank.

We are following two main lines of research, firstly: "The Role of Spirituality in the Search for Extra-Terrestrial Intelligence: A Survey of Undergraduate Students." The potential discovery of the existence of an ETI species in our galaxy might have a profound impact on our scientific, philosophical, and religious comprehension of humanity.

Considering that there are around 60 potentially habitable exoplanets according to the Habitable Exoplanets Catalog, the odds of such discovery have increased in recent years. The Search for Extraterrestrial Intelligence (SETI) research challenges us to deal with otherness and diversity in a more radical and profound sense. The quest of contacting the "cosmic other", which is crucial to the SETI research, is then closely related to the quest of knowing ourselves. The very process of investigating cosmic otherness enriches us with new perspectives.

As part of our research, we conducted a survey among undergraduate students of a group of Jesuit Universities in the United States and Latin America majoring in humanities, technical and scientific disciplines. The UCC belongs to the International Association of Jesuit Universities. This network has the potential of multiplying the impact of our project in different countries. Under this umbrella we have carried out the survey at Santa

Clara University (Santa Clara, USA), Ibero University (Mexico City, Mexico), and Javeriana University (Bogotá, Colombia). Our study will allow us to compare results coming from different cultural regions in the world.

Secondly, "Towards an encounter with an extraterrestrial civilization: motivations and new epistemological categories." We ask ourselves about objectivity and motivation in the scientific observer who goes to meet the Other, particularly, an extraterrestrial civilization with the categories of his/her world to searching with our own categorizations will allow us only to see civilizations like ours.

It is necessary to rethink and make the categories more flexible to allow the Other to appear and become present in its diversity. We should avoid forcing the Other to enter a category that excludes his/her diversity and could subordinate his/her in an asymmetric relationship.

In this encounter with the Other, we ask ourselves about the role of science: how do we go about meeting an extraterrestrial intelligence? With what kind of motivations? Spirituality could be a hermeneutical framework from which to prepare and understand a potential first contact with an extraterrestrial civilization.

This work was presented in the *Primeras Jornadas de Epistemología e Historia de la Astronomía*, Universidad Nacional de Córdoba (Argentina).

Father Matteo Galaverni

Last year my bishop, Mons. Massimo Camisasca, increased my time for research. Therefore, I had to leave the parish where I had lived for the last three years and move to an apartment near the Reggio Emilia Cathedral. The project was to have three weeks per month dedicated to research, mainly based in Castel Gandolfo, and one week in Reggio, continuing my pastoral work with university students.

But the Covid pandemic continued to change my plans over the year. In fact, the northern part of Italy was one of the first and hardest hit regions of the pandemic. In the province of Reggio Emilia, we have four big public hospitals. Usually there are hospital chaplains responsible for pastoral care. But they are all quite old, so they were not allowed to enter the hospitals after the first Covid cases started.

At the end of November, I received a letter from my diocese asking the younger priests to help in the hospitals. At the beginning I was quite skeptical…and even a little bit afraid (no vaccines were available in those days). It was not easy to enter in the Covid area; we had to wear a face shield, medical cap, two masks, two pair of gloves, shoe coverings, and a full protective suit (almost like in a clean room for experiments). But in the end, it was a very positive experience. We had profound encounters and conversations with a lot of people: patients, physicians, nurses, hospital attendees.

In the meantime, during my isolation periods at home and my visits in Castel Gandolfo, I continued my research activity. Together with Gabriele GIONTI, I completed the project on photon helicity and quantum anomalies. We studied the macroscopic effects on light polarization when an electromagnetic field is quantized in a curved spacetime. More details can be found in the published version of our paper.

I also continued my research on cosmic birefringence (limits on the rotation of Cosmic Microwave Background linear polarization) in collaboration with Fabio Finelli (INAF-OAS Bologna). Together with Paolo Beltrame and

Gabriele GIONTI we are also planning to start a new collaboration with INFN-Frascati. Working in particular with Danilo Babusci and Claudio Gatti, we would like to study analogue gravity and collaborate on projects related to axion physics.

Many of the conferences I attended and the seminars I gave last year were on-line, but it was very nice to have also some in-person events. I really hope to change this balance next year.

With the help of Giuseppe KOCH, who assisted me in consulting the Specola archive documents stored by Sabino Maffeo, I collected some information on Father Giuseppe Lais. We mark the 100th anniversary of his death at the end of this year, December 26. (See chapter 4.) He was the vice-director of the Specola for more than thirty years and guaranteed continuity with the Observatory of the Roman College, since he was also student and assistant of Angelo Secchi. I hope to publish some papers on him soon.

During last year I was quite often at the Specola on Sundays, therefore Robert Janusz and I started to lend a hand for the celebration of the Eucharist at the St. Francis chapel in Albano Laziale.

Christopher M. Graney

How astronomers over time have viewed the universe is a question of science and history. However, we today often imagine a story of astronomy that is based not on science and history but on what appeals to us. The appeal of imagined stories is a challenge that makes science history research valuable to the Vatican Observatory. These three ideas were at the heart of my work this year.

How astronomers during the "Copernican Revolution" viewed the universe has long been the focus of my research. That history is fascinating, dynamic, and complex, in part because during the seventeenth century the available data supported a Copernican universe that was not like our modern concept of the universe; rather, one in which the sun was the universe's unique, brilliant central body, with the stars being utterly different from it—giant and dim.

Johannes Kepler ably showed this. A Copernican, he embraced the giant stars, seeing in them the power of God made manifest. But other astronomers, including various members of the Society of Jesus, followed Tycho Brahe in rejecting the giant stars as an absurdity, an *ad hoc* solution to the Copernican system's parallax problem—and in rejecting Copernicanism. This year I was able to publish several papers that shed additional light on both Kepler's ideas and those of the Jesuit anti-Copernicans.

Those papers added to the fascinating, dynamic, and complex history of the Copernican Revolution that historians have been building for decades. Nevertheless, we today often ignore the progress that has occurred in this history, imagining instead that an older, simplistic story remains valid: that anti-Copernicans, for reasons of religion or academic tradition, denied science and conspired to reject it, refusing to accept clear scientific proof of the Copernican system and even refusing to look through a telescope.

The extent to which we hold to this story was made clear to me this year by several new books that promoted it—all written, disappointingly, by credible authors, and published by well-known publishers. This prompted me to publish two reviews of this simplistic story, one in a scholarly Catholic journal, the other in a more popular magazine for "sceptics".

That magazine has long addressed the issue of people imagining conspiratorial stories that conflict with scientific or historical evidence (or simply with reason). In 2021 people seem to be imagining such stories regarding a growing list of things, such that today is sometimes called a "post-truth" or "post-fact" age.

That is a challenge for institutions that value and hope to discover Truth, institutions such as science and the Church. The Vatican Observatory is part of both. Thus researching the history of the Copernican Revolution seems to me broadly valuable, whether that work leads me to publish in a scholarly journal or in an unusual magazine.

Science history has been valuable in my non-research work this year, too. This spring I assumed new responsibilities with the Vatican Observatory Foundation in the area of Public Relations. This work primarily involves writing popular-level articles about the Observatory on one hand; an edited volume of the works of former Director Fr. George V. Coyne, SJ on the other.

Science history has played a role in these—it seems history appeals to broad audiences, and Fr. Coyne often wrote on history. It has also played a role in my other work with the Foundation, and in related work I have undertaken in my local archdiocese. I am happy to be an astronomer and historian of science with the Vatican Observatory, contributing material for my third Annual Report.

Father Michael Heller

2021 was dedicated to my book, *Infinitely Many Universes: From Einstein to Infinity*, published in Polish. The modern story of the multiverse began with Leibniz. Although he treated "other worlds"' as mere possibilities, they played an important role in his logic. In a somewhat similar manner, the practice of cosmology presupposes considering an infinite number of universes.

Einstein field equations are a basic mathematical structure in cosmology, and each solution to these equations can be interpreted as a separate universe. Since the number of such solutions is infinite, we can truly speak of the "Einstein multiverse". Its status is not controversial. Moreover, cosmology itself could be regarded as a theory of "Einstein multiverse".

Indeed, theoretical cosmology tries to penetrate as many areas of this multiverse as possible, whereas observational cosmology tries to narrow the field of its inquiry to those regions of the multiverse which best correspond to the results of observations. The solution space of Einstein equations, i.e., Einstein's multiverse, has a beautiful, albeit highly sophisticated, mathematical structure which is subject to careful mathematical investigations.

The multiverse idea as a collection of existing "other universes" first appeared as an auxiliary concept in discussing the so-called anthropic principle, and then as a hypothesis that was supposed to solve some cosmological conundrums. Several chapters of the present book lead the reader through this labyrinth.

From the point of view of the philosophy of science the question should be asked: Could the explanatory power of multiverse ideology compensate for the relaxation of empirical control over so many directly unobservable entities? Is the appealing to a possibly infinite number of

"other universes" in order to explain some problems in our world a justified strategy? With no strict empirical control at our disposal, it is logic that must take over. In all multiverse versions classical logic is (tacitly) presupposed. And what if logic could change from one world to another in the multiverse?

Such a possibility is suggested by category theory, a quickly developing branch of mathematics. From this point of view, our present concepts of the multiverse seem hopelessly "not enough". In category theory, logic is not something "imposed from above", but it is rather a part of the game. Moreover, there are strong reasons to believe that all mathematics is but an infinite space of such "categorical universes".

One of the physicists once said that the whole of multiverse business is not physics but theology. And what would a theologian say about the idea of the multiverse? He might say, for example, that since God is infinity, He might be more interested in an infinite number of universes than in a single universe.

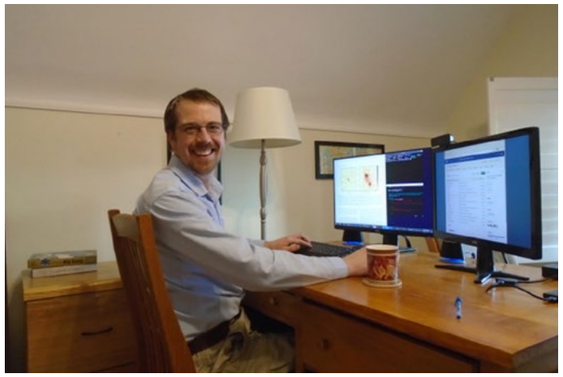
Father Adam Hincks, SJ

I began my faculty position at the University of Toronto in July 2020, in the midst of the pandemic, which made many aspects of my first year unusual. But in the autumn of 2021 the campus started opening up again, in an appropriately cautious and incremental manner, and I was finally able to start moving into my offices—in the plural, since I have two of them: one in the Department of Astronomy & Astrophysics, where my graduate appointment is and where currently I am doing most of my research, and the other at St. Michael's College, where I teach in the Christianity and Culture programme. As I write this, my next project for these offices is to get some pictures for the walls!

My research over the past year has been focussed in a couple of areas. First, I have been doing analysis of cosmic microwave background (CMB) data from the Atacama Cosmology Telescope (ACT), a six metre millimetre observatory in northern Chile. One of my interests is using the Sunyaev-Zeldovich effect, by which CMB radiation scatters off of ionised gas, to study galaxy clusters and their environments. For example, I led a paper (to appear in MNRAS) that measured the amount of gas in a filament between two clusters of galaxies, thereby probing the 'missing baryons'.

What are these missing baryons? Cosmological measurements show that only about 5% of the present-day Universe is made up of atomic matter, or 'baryons', with the rest being dark matter and dark energy. But of the baryons, less than 10%—i.e., less than 0.5% of the total mass-energy of the Universe (!)—live in galaxies as stars or cold gas. The vast majority of them are in warm/hot diffuse gas *outside* of galaxies, with much of it in the 'cosmic web', i.e., the filamentary structures that connect large clusters of galaxies. Because they are diffuse they are very hard to observe and have hence been characterised as 'missing'. Our work is thus part of a broad effort to characterise and understand this elusive component of our Universe.

The second area of my research is in developing new observatories, in particular, a new, multi-telescope CMB experiment, also based in Chile, named the Simons Observatory, as well as a multi-dish radio interferometer in South Africa called the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX). Both of these involve many researchers at several institutions, and I am working, together with some students, on developing specialised software for collecting and processing their large volumes of data.



And speaking of students, I have been growing a research group, and now have a few undergraduate and graduate students and a postdoctoral fellow working with me.

On the teaching side of things, in each of the winter and fall terms of 2021 I have taught a third-year undergraduate course called 'Faith & Physics'. It is one of several courses on science and faith offered in St. Michael's Christianity & Culture programme. In my course we are studying the ways in which faith and physics relate to each other, particularly through the lens of great natural philosophers and physicists such as Descartes, Maxwell, Einstein and Lemaître, just to name a few.

Class discussions are enriched by the fact that roughly half of the students are science or engineering majors, and the other half humanities majors. Coming from this variety of backgrounds provides us with a great variety of questions and perspectives. Currently I am preparing for a brand new undergraduate course, cross-listed between Astronomy and Christianity & Culture, called 'The Bible and the Big Bang', which will be taught in the winter term of 2022.

Due to the pandemic, I have stayed put in Toronto since the last report, apart from some summer vacation and annual retreat in rural Ontario/Québec. At one point I realised that I had shattered my record for number of consecutive nights spent in the same bed (almost a year)! And while I look forward to travel becoming a bit more normal, I am also curious to see how our global interactions—scientific and otherwise—will be modified moving forward, both due to the wide availability of video communications tools and the growing awareness of our collective need to reduce emissions.

Dante Minniti

This year I remained mostly at home doing research and teaching online, and continued working as Associate Editor for the international journal *Astronomy & Astrophysics*. In August 2021 stepped down as President of the IAU Commission on "The Local Universe" because my term ended, and now remain as past-President advisor for the next period (2021-2024). In October 2021 my alma mater, the Astronomical Observatory of Cordoba in Argentina, celebrated the 150th anniversary, and I was honored to give the invited Sarmiento-Gould conference. In November 2021 I was awarded a grant as one of the PIs of the Centre for Astrophysics and Advanced Technologies in Chile.

Also, this year's PlosOne report places me in the top 1% of world scientists. I am listed as a top astronomer in the country, with more than 500 refereed publications accumulating more than 20,000 citations, yielding index H=80. We have also launched astroedu.com, that is a unique online platform to teach Astronomy in Spanish.

With regards my research, I continued working on the ESO public survey VVVX (VISTA Variables in the Via Lactea Extended Survey), a 10-year long project to map the inner Galaxy in the near-IR. Among the many interesting new scientific results from this year, we have discovered over 5,000 galaxies in the Zone of Avoidance, publishing the VVV Near-IR Galaxy Catalogue beyond the Galactic disk.

We also discovered new globular clusters located in the Sagittarius dwarf galaxy and in the Galactic bulge, one of which is in the extension of a halo stream. We also discovered VVV-WIT-08, a very rare variable star in the Galactic plane dubbed the giant star that blinked. I have also published a few interesting research projects with former VOSS students, including the discovery of extra-tidal star candidates around the Galactic globular clusters NGC 2808, NGC 6266 and NGC 6397, a VVV survey near-infrared color catalogue of known variable stars, an analysis of the RR Lyrae density distribution from the Galactic Centre to the halo, and a study of globular cluster survival in the extreme environment surrounding the Galactic center, including the discovery of the innermost globular cluster VVV-CL002.

Father Giuseppe Tanzella-Nitti

As a former astronomer, and now a theologian, my activity as Adjunct Scholar at the Vatican Observatory concerns history and philosophy of science, theology-science dialogue, the philosophical dimensions of scientific research activity.

Analogously to the other researchers, my 2021 was characterized by the Covid-19 pandemic. Many events took place online, but in a limited number of cases I had the opportunity to take part in in-person meetings.

Among them, let me recall the 2021 Genova Space Festival held in Busalla-Genova, on last July 8-11. The festival is a yearly meeting open to astronauts, scientists, space economy operators and science popularizers. This year I suggested to promote an International Award open to young researchers. Fifteen graduate students submitted a paper on the subject "The Motivations for the Human Presence in the Space Exploration". Marco Borghi, an Italian space engineer won the Award presenting a paper entitled "Above and Beyond: A Holistic View of the Motivations for Human Spaceflight". During the Space Festival I was asked to give the public Lecture "Has Technology a Spiritual value?". The answer was definitely "yes", and this caused a grateful surprise among the audience…

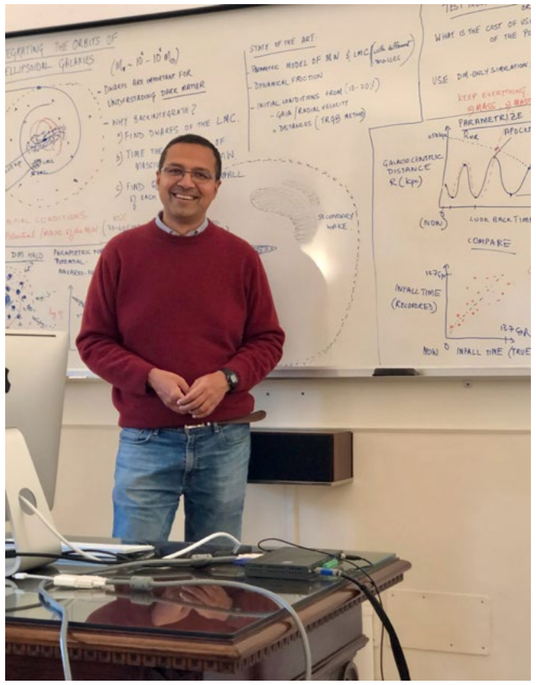
As you probably know, I also work as Director of the Interdisciplinary Documentation Centre for Science and Faith in Rome, which offers its academic partnership to the Vatican Observatory. The Centre runs the *Interdisciplinary Encyclopedia of Religion and Science* (inters.org), a registered philosophical journal (ISSN 2037-2329), and the *Advanced School for Interdisciplinary Research* (sisri.it), a program aimed to provide a philosophical-humanistic training for young scientists who wish to achieve a wider interdisciplinary expertise.

The seminars organized in the 2020/21 Academic Year started a 3-year cycle devoted to *Origins*. We began by exploring the origin of matter, in the last year; we investigate the origin of life in the present academic year, and will reflect on the origin of intelligence, during the next one. I contributed to the general discussion with a talk on "Creation of History and History of Creation: Do the Universe and Life Move towards a Fulfilment?".

The book *Scientific Perspectives in Fundamental Theology. Understanding Christian Faith in the Age of Scientific Reason* was accepted by Claremont Press and is now forthcoming. I hope to see it published within Spring 2022.

Finally, I am happy to share with you the on-line launching of the web platform DISF-Educational, especially designed for teachers and students at high schools, now available at disf.org/edu. The web platform offers Didactical Paths, answers to Big Questions, Videos and other resources to help addressing issues at the threshold of science, philosophy, history and religion. At the moment, the web site is in Italian, but we plan to prepare an English counterpart. To reach this scope, I plane to start a collaboration with the Science and Faith Initiative, at the McGrath Institute for Church Life, Notre Dame University, Indiana.

Memories of 2021



CHAPTER FOUR

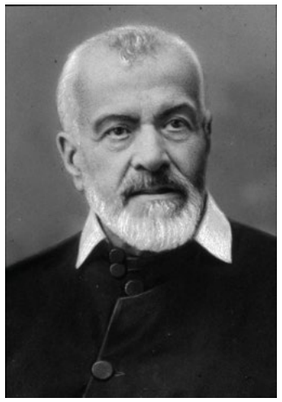
Father Giuseppe Lais (1845-1921):

On the Centenary of his Death

from the Roman College Observatory to the Vatican Observatory

On the hundredth anniversary of his death on December 26,1921, we recall the life and scientific work of the Oratorian Father Giuseppe Lais. A student and assistant to Fr.Angelo Secchi SJ at the Roman College Observatory, he was instrumental in the establishment of the Vatican Observatory. As Deputy Director for more than thirty years, his research activities covered many fields, from stellar photography, to meteorology, to the study of meteorites. He was also active in outreach to youth; among the boys he taught was the young Eugenio Pacelli, who became Pope Pius XII and who as Pope gave significant support to the activities of the Specola.

Giuseppe Lais was born in 1845, into a wealthy Roman family. As the eldest of thirteen children, he was sent to the prestigious *Collegio Romano* for his schooling where he met Father Angelo Secchi SJ (1818-1878). The Jesuit had recently built a new observatory on the roof of the St. Ignatius church where he carried out a stellar classification program that would lead to his being recognized as among the founders of modern astrophysics.



Fr. Giuseppe Lais (1845-1921).

Secchi noticed the talents of the young Giuseppe and brought him to work at the Astronomical Observatory while still a student. Lais graduated from the University of Rome in philosophy and mathematics, and in 1870 added a degree in architectural engineering to his academic curriculum before entering the Congregation of the Oratory of St. Philip Neri to fulfill his desire to become a priest. Lais' relationship with Father Secchi was further strengthened when he was appointed as an assistant to the Observatory of the Roman College, which laid the foundation for his remarkable expertise in instrumentation.

In 1873, the Roman College was expropriated and declared property of the Italian State; but thanks to Secchi's international reputation, the Observatory itself remained with the Holy See up until Secchi's death in 1878. In 1879, the Jesuits were forced to leave the Observatory. Lais decided to continue his research scientific at his home, where he set up a small observatory.

In 1875 he was a made a member of the Pontifical *Accademia dei Nuovi Lincei* (Roman Academy of the New Lynxes, modeled on the scientific society that once had Galileo as a member). During those years he also dedicated himself to the religious and cultural formation of young men and he counted the young Eugenio Pacelli (1876-1958) among his students. Pacelli accompanied Lais to Paris in the summer of 1896 on what was his first trip outside Italy. In 1899, when he was ordained a priest, Pacelli asked Lais to assist at one of his first Masses, celebrated in Santa Maria in Vallicella (Chiesa Nuova) which had been entrusted to the fathers of the Oratory. Thanks to this bond with Lais, Pacelli maintained his interest in the sciences, and astronomy in particular. As the Vatican Secretary of State, Pacelli stood beside Pope Pius XI at the inauguration of the new Vatican Observatory site at Castel Gandolfo in 1935. When he became Pope Pius XII, he supported the Specola and was instrumental in the purchase of a new Schmidt telescope, which he personally blessed in 1957.

In 1888, an exhibition of scientific instruments made by Italian clergy was organized by the Barnabite Father Francesco Denza (1834-1894) to mark the priestly jubilee of Pope Leo XIII. Following that exhibition, Denza and Lais suggested that the collection of instruments not be dispersed, but used in a series of studies aimed at demonstrating the Church's interest in the sciences. The collection was placed in the original seat of the Vatican Observatory, a large tower that crowns the small city state and is known as the Tower of the Winds (Torre dei Venti). Pope Leo XIII approved the refoundation of the Specola with the *motu proprio, Ut Mysticam* in 1891 appointing Denza as director and Lais as the deputy director.

The new Specola gained immediate international recognition by participating with 17 other observatories in producing a photographic map of the sky, the *Carte du Ciel* project, consisting of both the *Astrographic Catalog* and the *Sky Chart*. The Vatican's participation in this project gave an immediate direction to the activity of the newly reconstituted Specola. All the participating scientific institutes used a telescope of the same characteristics for the photographs, in order to ensure uniform results. Thus the Specola purchased the equatorial photographic telescope – known simply at the *Carte du Ciel* – which was placed at the highest point of the Vatican gardens, on the Tower of St. John.

In the first three volumes of *Publications of the Specola* (1891-1893) Lais published several notes on shooting stars, and accounts of his trips to Paris to learn how set up the photographic work. Subsequently, Lais' main task was astro-photography, with the observation log for the period between 1892 and 1903 recording 417 nights when he was at the telescope. Each of the 570 photographic plates of the *Carte del Cielo* consisted of a triple exposure, requiring about two hours of work. For the 1040 plates of the *Catalog,* on the other hand, a shorter exposure could be employed, since the *Catalog* was limited to objects up to the eleventh magnitude.

In 1904, Archbishop Pietro Maffi of Pisa was appointed by Pius X to be president of the board of directors of the Specola. He advised the Pope that "the personnel of the Vatican Observatory form a real religious family, similar, if not perhaps even identical" to that formed by the writers of *La Civiltà Cattolica*. Father Johan Hagen, director of the Jesuit observatory of the Georgetown College in Washington, was called from America to be the new director. Lais was reappointed as deputy director and continued his photographic work for the *Astrographic Catalogue* without interruption. Lais also intensified his activity within the *Accademia dei Nuovi Lincei*, of which he had become president. In the *General Index of Scientific Works* of that academy there are more than ninety contributions in his name. Among these we find an interesting contribution on the mineralogical and meteorite collection donated to the Specola by Adrien Charles, Marquis de Mauroy (1848-1927). It emphasized the importance of the collection for research activity and mentioned possible spectroscopic studies on meteorites.

In June 1921, due to ill health, Lais asked to be relieved from the office of president of the *Lincei*. A few days before his death, he received a letter of commendation from Benedict XV, accompanied by a gold medal, to thank him for his long service to the Holy See. He died in Rome on the morning of December 26, 1921.

At his death, only six of the 1040 photographic plates for the *Catalogue* to which the Specola had committed remained to be completed; 277 of the 570 plates envisaged for the *Sky Atlas* had been made. In 1942 the *Carte du Ciel* telescope was transferred to the Pontifical Gardens in Castel Gandolfo. After the war it resumed photographic work and by 1955 the last plates were finally published.

The astounding fact is that the activity related to this project continues even to this day. For some years now, the digitization of the photographic plates of the Specola has been underway (see Omizzolo's entry in chapter 3). This can offer today's astronomers a valuable point of reference on the position of the stars at the time when the plates were taken. The same telescope used by Fr. Lais has been completely restored and it will soon be open to visitors within a museum and Visitor's Center, being set up at the domes of Villa Barberini in the gardens of the pontifical residence of Castel Gandolfo.

In addition to his numerous publications and photographic plates, Fr. Lais' beautiful testimony of a life of service to the Church and to science is inspiring. In difficult times he succeeded in remaining faithful to the dual vocation of priest and scientist. As such he is honored in the city of Rome, with a street and a school in the Laurentina area bearing his name.

Fr. Giuseppe Lais remains a key figure in particular for the Vatican Observatory, not only for working toward the refoundation of an observatory in the Vatican from as early as 1879, but above all for his faithful service as deputy director for more than thirty years, under three Popes and three directors. Essentially, his position as the last of Secchi's disciples cemented the link between the Roman College Observatory and what would become the Vatican Observatory, *la Specola Vaticana*.

Matteo Galaverni, Giuseppe Koch, SJ

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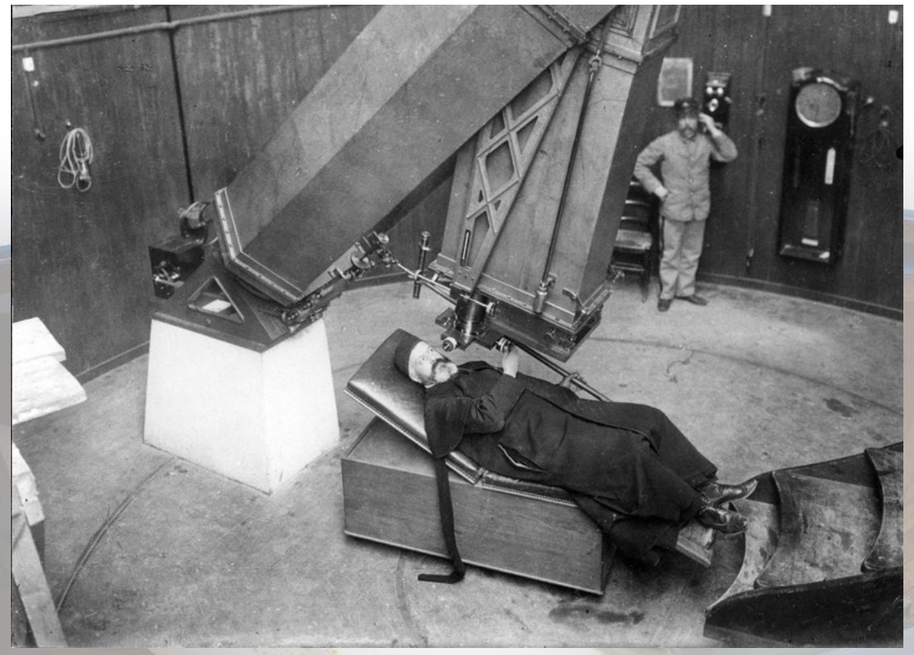
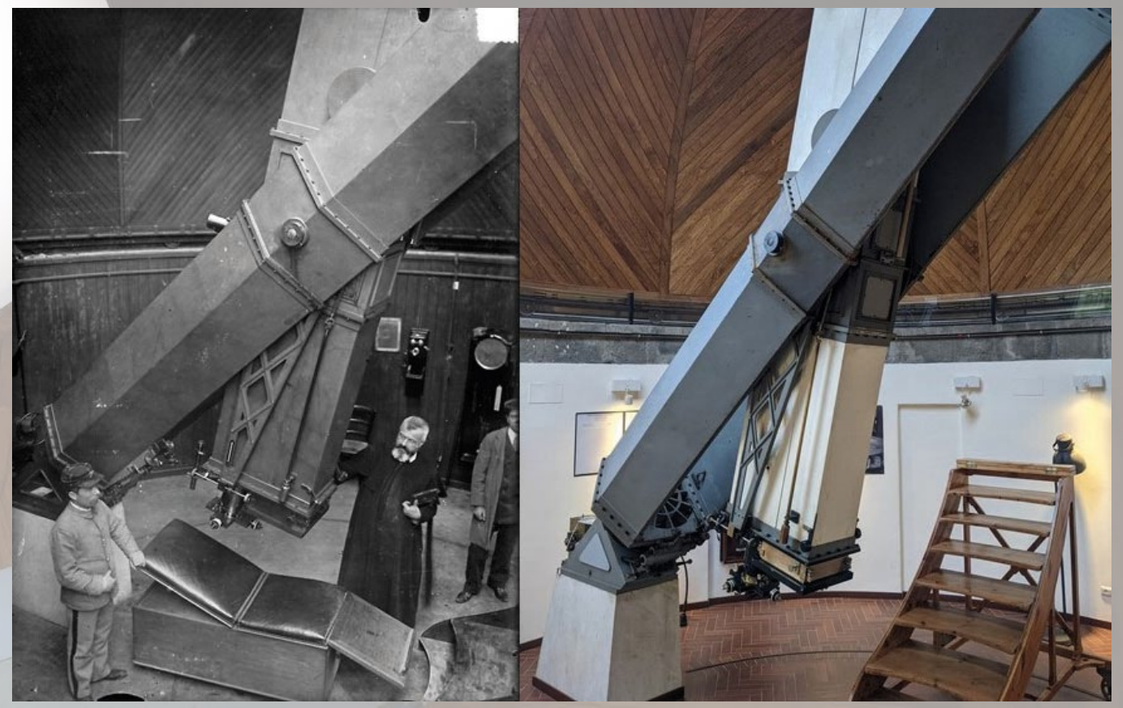


Lais observing at the telescope Cate du Ciel in theVatican.



Left: equatorial photographic telescope Carte du Ciel with Lais and Specola keeper Carlo Diadori. Right: same telescope in 2021 at the domes ofVilla Barberini.

Lais in his office in the Tower of theWinds.

Specola offices in the Tower of theWinds.

Pope Pius XII observing at the Schmidt telescope (Castel Gandolfo, 1957).

CHAPTER FIVE

Instrumentation and Technical Services

Observations at the VATT gathered pace with the easing of Covid-19 restrictions in 2021, allowing a much need boost to the quality of operations on Mount Graham and even the training of new observers.

Vatican Advanced Technology Telescope VATT

Realuminization of the VATT Mirrors

The single most important action of 2021 regarding the VATT (the Alice P. Lennon Telescope and Thomas J. Bannan Astrophysics Facility) was the realuminization of both the primary and the secondary mirrors (M1 and M2). Gary Rosenbaum's records show the initial coatings as follows: The first M1 coating, October 30, 1992, failed. The second attempt, November 4, 1992, was successful. It was installed in the mirror cell on Mt Graham in 1993. Subsequently it was recoated in 2002, 2007, 2013, and now in 2021, i.e., after of 9, 5, 6, and 8 years of service, respectively.

The M1 coating was carried out on August 6 (rate of deposition 6.0 nm/s; total thickness 95.2 nm). M2 was initially coated on August 27, 1993, and then recoated on July 24, 1997. No other M2 coating was carried out until August 20, 2021 (rate of deposition 7.4 nm/s; total thickness 100 nm). The coatings were done by Gary Rosenbaum and Joe Hoscheidt, assisted by Paul Smith and CORBALLY, at Steward Observatory's Sunnyside facility.

To hoist the mirror and other elements, Eric Buckley, MGIO director, arranged for the City of Safford's boom truck with a remotely operated crane. Michael Franz and Summer Franks took the remote-control pendent to Steward for cleaning of the potentiometers. The disassembly, M1 removal, transport, and subsequent M1 installation and telescope assembly was carried out by Gary Gray, Summer Franks, Chris Johnson, and Joe Hoscheidt led by Michael Franz. Steven Harmon, Larry Thomas, Armando Alvarado, and April Morton (MGIO) provided competent and enthusiastic assistance on site.

A time-consuming side project was the replacement of the 36 pneumatic diaphragms (manufactured by Marsh Bellofram) that support most of M1's weight. Spacer rings were manufactured in record time by the University specialist machine shop (Arizona Research Laboratories, previously URIC). Diana Vargas assisted Michael Franz.

Michael Franz led the effort, summarizing:

- Both mirrors bear fresh, beautiful coatings.
- The thirty-six Bellofram mirror supports have been overhauled, with new diaphragms.
- The mirror cover has been cleaned (Gary Gray).
- New magnetic sealing strips for the front primary-mirror seal have been fabricated and installed (Gary Gray).
- The thermal system has new A-to-D units and seems more stable (Summer Franks).
- The large spotting scope objective is clean.
- The bellows around the primary center-hole baffle is in and looks good.

The removal, transport, aluminization, reinstallation, and all other aspects of this M1 maintenance operation were covered by the University of Arizona. Only the M2 portion of the effort was charged to the Vatican Observatory.

BOYLE was the first user (night of October 2) of the newly realuminized VATT. The timing allowed us to obtain good quality data with GUFI capturing the occultation of a 15th magnitude star by Neptune (Nepture Occultation Campaign - NOC21; led by Damya Souami, from Paris Observatory LESIA) late on the evening of October 6. We purchased a 2" x 2" CH4 filter for the occasion.

VATT Upgrades

Several upgrade projects continued: network, commissioning of the guider box, and the automated collimation and collimation maintenance procedure. Following up on last year's work, Gary Gray supervised replacement of the compressors in the hydrostatic-bearing oil chillers by Advanced Air Systems, LLC.

Personnel

Daniel Avner left Steward Observatory's Mountain Operations group, and the VATT team on November 24, joining Caltech.

Safety and Covid19

The presence of observers and other personnel in the observing period of 2021A (February-July) continued to follow the same UA guidelines as 2020B (August-January), i.e., a one-person limit at the VATT facility at any given time, with some exceptions for daytime duties with PPE and distancing. The 2021B (August-January) period brought a slight easing of these measures, viz., two observers/operators were allowed to work in the control room through the night. This allowed us to train new observers who had been waiting for an opportunity to use the VATT since early 2020.

At Castel Gandolfo

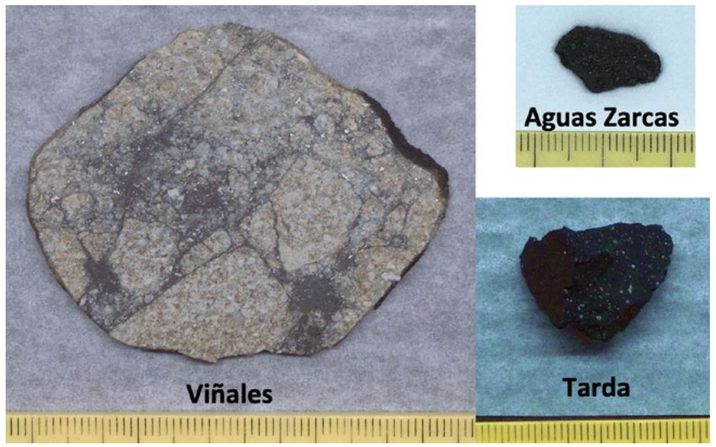
High Performance Computing at the Specola

This year, the Specola in Castel Gandolfo initiated a small step in the direction of high-performance computing (HPC). It acquired a multi-processor Dell Poweredge Server to cater to the high-performance computing needs of the researchers based at Castel Gandolfo. The current configuration is also capable of analyzing large simulations as well as processing large datasets.

Meteorite lab

This year, the meteorite laboratory has grown by a few specimens. Among donated specimens are two nice pieces given by Joachim Karl of Germany. One is a 0.7-gram piece of the CM2 carbonaceous chondrite Aguas Zarcas, that will be turned into thin sections. Another is a 19.5-gram slice of the L6 ordinary chondrite Viñales, which fell in Cuba in 2019. We also acquired a 4.3-gram piece of the ungrouped carbonaceous chondrite Tarda.

The growth of the Vatican meteorite collection is largely dependent on the generosity of benefactors. We are grateful for the many people who have given us specimens in the past.



Meteorites added to the collection this year.

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Realuminizing the VATT Mirror: *Top row, from left: Removing the mirror from the telescope dome, July 31, photo credit Joe Hoscheidt. Reinstalling the mirror, September 15, photo credit Gary Gray. Mirror remounted in telescope, September 28, photo credit Gary Gray. Bottom row, from left: Removing the mirror from its mounting, July 30, from left Chris Johnson, Michael Franz, Larry Thomas, Joe Hoscheidt, photo credit Summer Franks. In the realuminizing facility, August 8, from left Joe Hoscheidt, Paul Smith, and Gary Rosenbaum, photo credit Chris Corbally. Preparing the mirror to be aluminized, August 6, photo credit Paul Smith.*

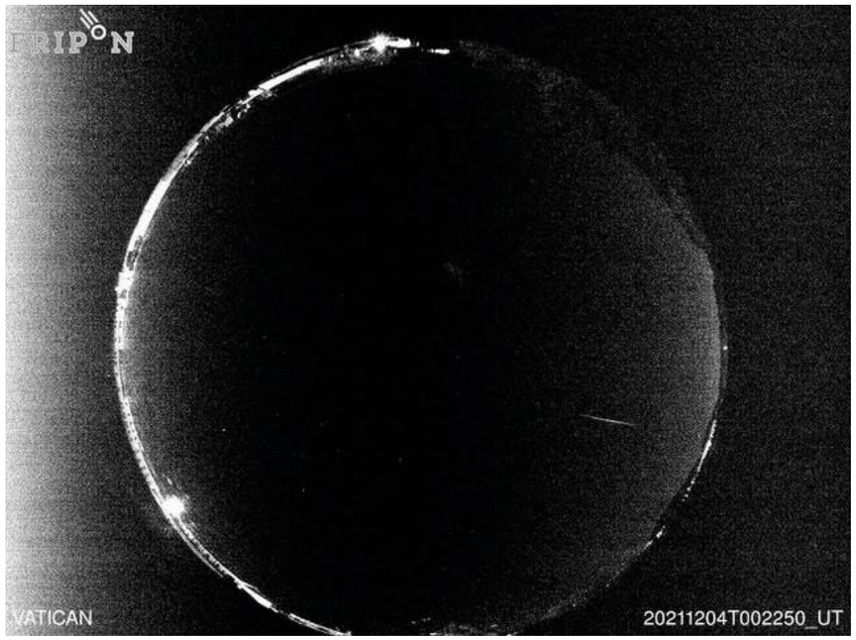
FRIPON

In late November, we installed an all-sky camera in Castel Gandolfo to record bolide events as a part of the FRIPON (Fireball Recovery and Inter-Planetary Observation Network) network of identical cameras across western Europe. They are designed to study interplanetary matter by detecting and characterizing fireballs and when possible to recover fresh fallen meteorites. With multiple detections of fireball events from at least three different locations, it becomes possible to compute their trajectories and orbits.

Bright events recorded by these cameras might actually drop meteorites and so knowing these parameters can allow us to compute the location of of meteorite strewn fields and organize the search for these samples. In addition, the accumulated data can provide the material for a statistical determination of the origins and possibly the parent bodies of the detected fireballs and the interplanetary particle impact flux.

It joins similar networks in southern Arizona in which Fr. KIKWAYA-ELUO participates.

The FRIPON camera on the roof of the Specola in Castel Gandolfo.

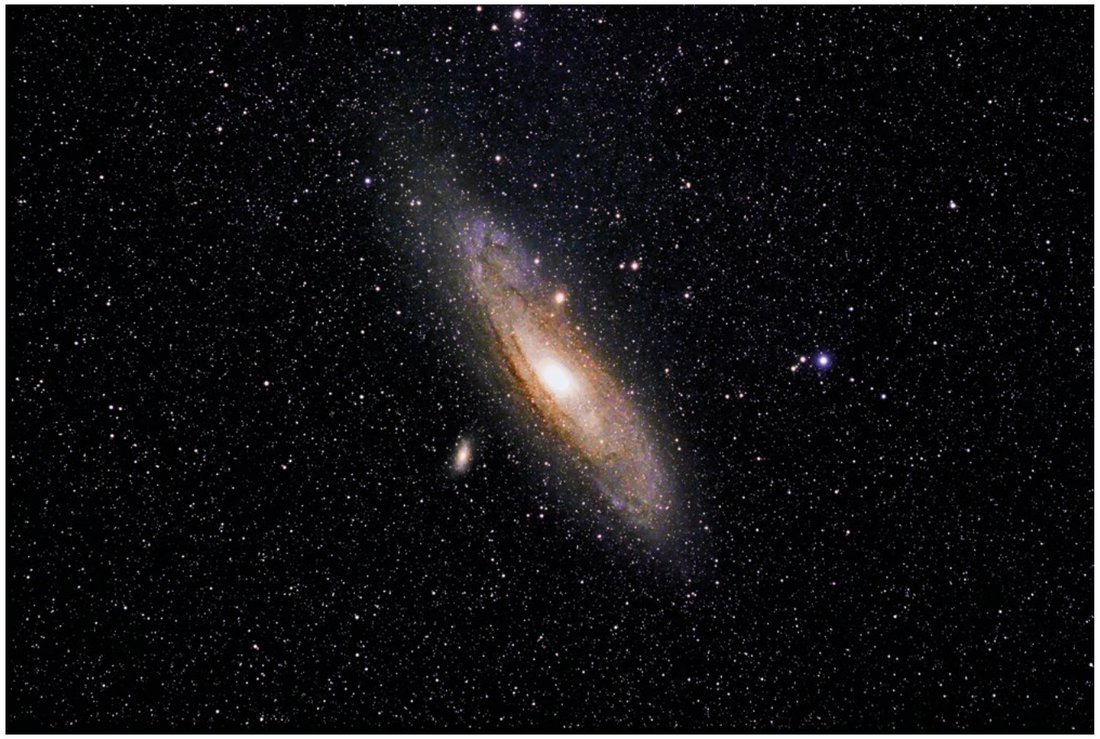


On December 4th, even with the rainy weather, we got our first result.

RedCat

In the fall, thanks to a generous donation, the Specola obtained a William Optics Redcat 250 f4.9 wide field astronomical camera lens. This lens is used by COSTA to image notable astronomical objects for use in our outreach website and documents. It provides sharp imaging of stars across a wide field of view; with the QHY268C CMOS camera its field of view is 5° x 3.5° which is comparable to the historic Schmidt telescope in the papal gardens. An example of what this telescope can do is shown in the image of the Andromeda Galaxy shown here; this galaxy is more than three degrees wide and capturing the entire galaxy plus its satellite images without coma or chromatic aberration is difficult to impossible for most large telescopes.

The RedCat telescope.



The Andromeda Galaxy M 31, a stack of seventy images each exposed for 15 seconds with a QHY268C CMOS camera on a Rainbow Astro RST135 mount.

CHAPTER SIX

Education and Outreach

2021 revealed a new normal spent in lockdown, working remotely on science and research with only a few opportunities to travel to in-person seminars, conferences and workshops. The pandemic has forced education and outreach to embrace developing communications technology.

Education and Public Outreach

BROWN gave a series of talks at Regis Jesuit High School in Denver, Colorado.

CONSOLMAGNO gave an online astronomy class for high school students with the Arrupe Virtual Learning Institute.

For the VO Sacred Space blog, CORBALLY described three characteristic occasions in "Remembering Jesuit Brother John B. Hollywood, SJ."

GABOR gave a brief virtual tour of the VATT facility, spoke of telescope optics and gave a demonstration of convex lens's magnifying power and focal length for the *Science Den* (Vedecký brloh), a hand-on science program for children, sponsored by the Slovak Academy of Science, on January 23; online only due to Covid19.

He gave a presentation and organized Vatican Observatory's virtual exhibit at the second COFAS (Conference on Faith and Science) and he gave an online talk on Maximilian Hell for the School in Porubka pri Sobranciach, Slovakia.

In the summer, with the easing of restrictions, GABOR travelled to give a public lecture at the Observatory and Planetarium in Presov, and at the Observatory and Planetarium in Zdanice, in the neighboring Czech Republic, on August 29.

GIONTI delivered an online talk on "A short and popular introduction to Quantum Gravity and Quantum Cosmology" for the series of seminars "Ortiz-Chardin" of the Pontifical University Javeriana, Bogotà, Colombia.

He also gave an online talk on "Cosmology and *Creatio ex Nihilo*" for the Master's in Science and Theology of the Pontifical University *Regina Apostolorum*, for the Club of Amateur Astronomers "Astrocampania" and in person at the IV Gran Sasso Forum at the University of Teramo, Abruzzo.

GIONTI also addressed "The Scientific tradition of the Society of Jesus" for the Italian Society of History of Physics and Astronomy in an online talk in April and "A Journey in the Universe," for several elementary school classes in Polleza, Marche, in May.

MACKE gave an online talk to the Bishop DuBourg High School "Big History" class in St. Louis Missouri and an online public talk for the Roger That! Conference, Grand Valley State University, Grand Rapids, Michigan, on "The use of 3d scanning and computer models in the laboratory study of extra-terrestrial materials".

FRANCL-DONNAY gave a number of public presentations (online) including "Amid the Burning Layers of Grace" St. John Vianney Center, in January; "Steal Her Bones" Talkback, InterAct Theatre Company, in February; "Probing the Shallows of the Unknown: A Magi Project Evening Conversation" Collegium Institute, and "Amid the Burning Layers of Grace: Science as Prayer," MIT Catholic Community, both in April; "Molecular Monsters: Designing molecules with Möbius structural topology" Queens College, in May; "The Write Stuff" RNA Institute, SUNY Albany, and "A Brief History of Water in the Universe" Tri-College Sages, both in November.

FUNES continued to teach a class on Philosophy of Nature and begun to teach Theology of Creation at the School of Theology at the Universidad Católica de Córdoba and gave lectures to Universities and high schools by Zoom on topics related to Astrobiology, Science and Faith.

GALVERINI gave public lectures on "Faith and Science: a possible dialogue," at the Università Cattolica, Piacenza; "Angelo Secchi" at the Angelo Secchi High School, Reggio Emilia, and "Alza lo sguardo…" at the Centro Don Bosco, San Felice sul Panaro.

MINNITI gave public lectures on "Millones y millones de planetas habitables" at Universidad de Los Andes, Bogotá, Colombia; on "Exoplanetas: habitar otros mundos" at Universidad Austral, Curicó Chile, and online at the 63rd Meeting of the Asociacion Argentina de Astronomia, on "Reflexiones sobre el Observatorio Astronomico de Cordoba", Cordoba, Argentina. He also gave an invited colloquium entitled "The VVV Extended Survey of the Milky Way" at the Bowling Green State University, Ohio and public talks at Universidad Andres Bello.

News and Media

The launch of the new www.vaticanobservatory.org website became the opportunity for significant press coverage. Most notable was a lengthy interview with CONSOLMAGNO and MACKE conducted by Sylvia Poggioli, Senior European Correspondent for US National Public Radio.

Among other media interviews: CONSOLMAGNO appeared on the Austrian television program *FeierAbend*, which was aired on Epiphany Day (January 6); several interviews for Vatican Radio; a special feature on EWTN; the Katie McGrady Show on the Catholic Channel of Sirius XM satellite radio; the *Constant Wonder* show on Brigham Young University radio, Provo, Utah; and the BBC radio program "Heart and Soul".

CONSOLMAGNO appeared on Moriba Jah's *Vox Populi* Podcast *https://spacewatch.global/2021/02/space-cafe-recap-moribas-vox-populi-03-on-religion-ethics-and-space/* ; podcasts of the Sky Watcher Podcast, and the European Space Foundation; "The Rational View" podcast; and "Why We Explore", a podcast supported by the National Endowment for Humanities.

CONSOLMAGNO was a subject of the "Where I work" feature published in the back pages of *Nature* on October 14. Greg Levy, the editor in chief of the new Irish Catholic magazine *Leaven*, featured an interview with CONSOLMAGNO for its premiere issue. He was interviewed for *L'Eco di Bergamo*; *Kerk & Leven* of Antwerp, Belgium; *Božje okolje* from Ljubljana, Slovenia; the French Catholic magazine *La Vie*; in *Rupertusblatt*, the weekly


The back page

nature
International journal of science

Where I work
Brother Guy Consolmagno

I spend a lot of time looking upwards. Here, at Castel Gandolfo, outside Rome, I'm peering through the Vatican Observatory's historic 1891 telescope. It can't compete with Rome's light pollution and is mainly for fun and tourism – we're hoping to welcome visitors again soon – but cloth next to a piece of scientific equipment helps to tell that story.

All 12 staff astronomers at the observatory are either priests or Jesuit brothers like myself, but you don't have to be Catholic to use our facilities. We collaborate with other astronomers and graduate students from

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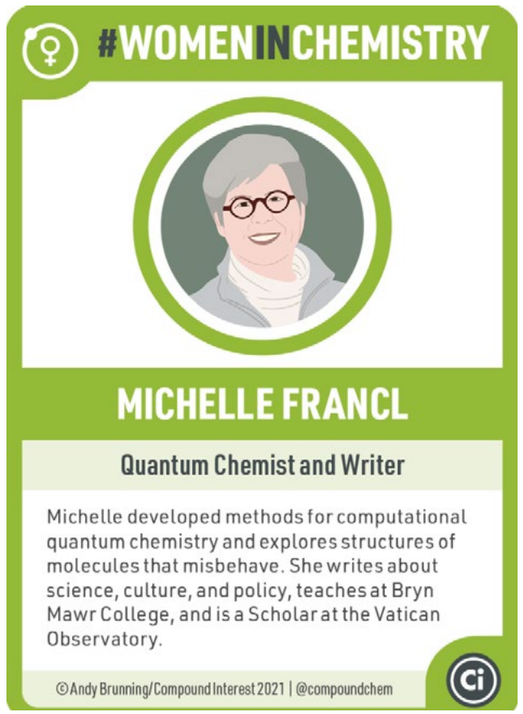
newspaper of the archdiocese of Salzburg, Austria; *LMU Magazine*, from Loyola Marymount University of Los Angeles; and *The Irish Catholic* of Dublin, Ireland.

CORBALLY on March 9 was interviewed about "Stars" by Andy Salvatiera, Edward de Castro, Gabo Sabastian, and the ACY team for the *YTV* Show of the Archdiocese Commission on Youth Manila, Philippines. On May 11 he discussed with Drew Mariani on *Relevant Radio* the prospect of a common Easter date for Catholics and Orthodox Christians, and on July 28 about how our universe might be a giant three-dimensional donut, a proposal of Thomas Buchert, Lyon.

He was interviewed on December 9 by Jeremy McGowan of UAPX for Osiris Impact Episode 3, and discussed the Catholic Church and Science with Matthew Szydagis (U Albany).

D'SOUZA'S work was featured in *Sky and Telescope* this year (*https://skyandtelescope.org/astronomy-news/local-dwarf-galaxies-history/*). An article about a series of online public lectures were written up in a local newspaper in his home province of Goa: *https://www.thegoan.net/goa-news/goan-priest-wows-audience-on-key-issues-of-astronomy/70823.html* He was interviewed by Sony Productions for one of their podcasts called "Go-Beyond" available at *Apple Podcasts*, *Spotify*, *Google Podcats* and *Amazon Music*: E.g *https://apple.co/3wgVrGh*



GABOR gave an interview to the *Ecclesia* podcast, on January 20, and another to Tibor Gorfol, editor-in-chief of *Vigilia*, a Hungarian Catholic monthly founded in 1935, (*Vigilia*, 86 (2021) 7, pp. 536-543).

GIONTI was interviewed with CONSOLMAGNO and GABOR by Mark Rayner, deputy editor of CERN *Courier*, "Quantum Gravity in the Vatican". He was also interviewed by Elisabetta Mirarchi of the TV station *RAI1*, TV program "Speciale TG1", for a documentary on UFOs.

MACKE was interviewed by Yasmene Warren (NSM Today) on the Lucy mission launch, 12 October 2021, Orlando Florida; by Sylvia Poggioli (NPR) in May for *The Vatican's Space Observatory Wants* to *See Stars and Faith Align*; by Glenda Meekins (Florida Catholic) for *Can science and faith collide?* April 21; by *Catholic News* Service's Carol Glatz about the Perseverance rover on Mars for the article, "Mars missions can inspire next generation scientists, papal astronomer says" published on Feb 19, 2021.

He was also interviewed by *Radio Vaticana* about the Perseverance rover on Mars which appeared online in, "La sonda della Nasa 'Providence' su Marte nel segno di Guglielmo Marconi"; and in the podcast Il *Mondo alla Radio*, Vatican News, "La missione di Perseverance su Marte. Il prossimo passo è una spedizione umana?" February 19, 2021.

MACKE was interviewed by *Pegasus Magazine* (Univ. Central Florida magazine) about Vatican Observatory, Faith, Science, and his experience as an alum of UCF, titled "The Pope's Meteor Man" in the Spring 2021 issue.

FRANCL-DONNAY gave an interview with Kirsten Hall for Chemistry World on the topic "coordinative bonding to carbon more nuanced than first thought" (*https://www.chemistryworld.com/news/coordinative-bonding-to-carbon-more-nuanced-than-first-thought/4013330.article*).

She spoke on "Unlocking the Mysteries of the Universe" with Ira Pastor for ideaXme. (*https://radioideaxme.com/2020/11/13/unlocking-the-mysteries-of-the-universe-molecules-particles-and-people/*) She spoke with Joshua Howgego for *New Scientist,* under the title, "Physics might create a backdoor to an afterlife – but don't bank on it." (*https://www.newscientist.com/article/mg24833122-200-physics-might-create-a-backdoor-to-an-afterlife-but-dont-bank-on-it/*).

She also appeared in a ChemTalk YouTube interview (*https://www.youtube.com/watch?v=IcjpwQgl99Q*). Finally, she was honored with a #WomenInChemistry collector's card (*https://i0.wp.com/www.compoundchem.com/wp-content/uploads/2021/03/033-Michelle-Francl.png?fit=750%2C1050&ssl=1*)

CORBALLY was interviewed about "Stars" by Andy Salvatiera, Edward de Castro, Gabo Sabastian, and the ACY team for the YTV Show of the Archdiocese Commission on Youth Manila, Philippines.

HINCKS was interviewed by Jennifer Zhong, 'Michaelmas: Carrying traditions into the future' in *The Mike*, a student newspaper at St. Michael's College, University of Toronto and he wrote a short popular-level piece: Adam D. Hincks, 'What Moses and NASA's Mars Rover taught me about wonder and awe', *America: The Jesuit Review* [online], 5 March 2021.

Presentations, Academic Activities and Conference Participation

BOYLE was first author on a poster paper at the 237th (Virtual) Meeting of the American Astronomical Society, January 10 - 15. In addition, he participated in the online EDEN collaboration workshop on December 16 - 17.

CONSOLMAGNO and MUELLER presented a paper on "Jesuit Observatories and Jesuit Science" as part of the "Science in the Service of Religion" sesions at the Scientific Instrument Commission virtual symposium, July 30.

CORBALLY continued regular online meetings with the Spectroscopy Discussion Group describing his recent spectral classification work and observing with VATT. With Margaret Boone Rappaport he presented for the Institute on Religion in an Age of Science Webinar Series, Science, Religion, and Society, on January 28. Their topic was *Extraterrestrial Species: Will they be moral? Will they be religious?*

During March 2–4 he joined in the Cool Stars 20.5 virtual meeting via Slack and Gathertown.

He participated as President of the National Committee for the Vatican City State to the International Astronomical Union in its triennial General Assembly. These business meetings were held online over the period August 19–26.

D'SOUZA took part online in the European Astronomical Society Annual Meeting in early summer and in the Scientific Instrument Commission XL Virtual Prague symposium during which he presented a paper on the "Historical collections of the Specola" with Ileana CHINNICI.

GABOR taught a course on the history and philosophy astronomy, ASTR 320, in the Spring 2021 semester at the UA. He participated in the EDEN collaboration workshop on December 16-17. GABOR also attended an online conference dedicated to Maximilian Hell as a part of *The Days of Maximilian Hell* event on May 12, commemorating his 201st anniversary of his birth (the 200th anniversary celebrations rescheduled), presenting a talk on Jesuit astronomers and the Theresian enlightenment.

Thanks to the stronger internet capabilities in Castel Gandolfo, GIONTI was able to take part in a number of online conferences. These included the International Conference "Quantum Gravity, Higher Derivatives and Non-locality", Moscow, Russia, March 8-12; the International Conference "The Quantum and the Gravity", April 26-30, 2021, where he spoke on "Canonical Analysis of Brans-Dicke Theory Addresses Hamiltonian In-equivalence between Jordan and Einstein Frames"; in the International Conference "The Atlantic General Relativity Meeting", Bishop University, Canada, May 25-28, where he spoke on "Hamiltonian Brans-Dicke Theory and Jordan and Einstein Frames" and the International Conference "Quantum Gravity and Cosmology" in honor of the 100 years of Sakharov, Moscow, Russia, June 8-12, 2021.

Gionti at the 24th meeting of the Italian Society of General Relativity and Gravitational Physics in Urbino, Italy.

He also participated in the first online workshop of the International Society for Quantum Gravity, Odense, Denmark, in October and the online workshop in honor of C. Storaiolo, Naples, Italy, December 1-3. He attended the XXIV international conference of the Italian Society of General Relativity and Gravitation, September 7-9, Urbino, Italy; and the annual FLAG (Fields and Gravity, Specific initiative of group IV of INFN) gathering in Bologna, Theoretical Physics Department, 21-22 December.

KIKWAYA-ELUO took part in three online workshops hosted by The Lunar Surface Science workshop of the USRA – Lunar and Planetary Institute. The first was on Space biology, January 20-21, the second on Structuring Real-Time Science Support of Artemis crewed Operations, February 24-25 and the third on Fundamental and Applied Lunar Surface Research in Physical Sciences, August 18-19. He also attended the 2021 Conference for African Astronomical Society, held online, Cape Town, South-Africa, March 8 and the 2021 Conference for Division Planetary Sciences, held online, October 3-8.

MACKE participated in the following online conferences: the 53rd Division for Planetary Sciences (DPS) of the American Astronomical Society; the Lunar and Planetary Science Conference 2021; the 2021 NASA Exploration Science Forum & European Lunar Symposium, and the 11th Joint Planetary & Terrestrial Mining Sciences Symposium and Space Resources Roundtable.

CHINNICI and D'SOUZA participated in the XL SIC Symposium, 26th ICHST held online, presenting "The Vatican Observatory Historical Collections: a different perspective on science-religion connection," July 25-31. CHINNICI also presented a paper on "Theodor Bredikhin and the Italian Spectroscopic Society" at the VII Bredikhin Conference, Zavolzhsk, Russia, May 24-28 which was held online, and she presented a paper at the LISA IX online conference "Creating and sharing a LAM (Library, Archives, Museum) digital collection". CHINNICI presented the Osterbrock Prize Lecture at the 237th Meeting of the American Astronomical Association on January 11 on "Decoding the stars': a recent biography of Padre Secchi".

GALVERINI attended the following online workshops and conferences in 2021: "Quantum Gravity, Higher Derivatives and Nonlocality", International Online Workshop, March 8-12; "The Quantum and The Gravity 2021", International Online Workshop, April 26-30 and the "16th Patras Workshop on Axions, WIMPs and WISPs", Online Workshop, June 14-18.

GRANEY attended the 2021 conference of the Society of Catholic Scientists, June 4-6 in Washington, D.C.

HELLER attended the conference "In the footsteps of the Archbishop of Życiński: Philosophy – Theology – Culture", delivering a talk titled "Józef Życiński's struggles with language about God" November 28-29, Kraków, Poland

HINCKS presented "A Cosmic Filament Illuminated by the Cosmic Microwave Background" at a colloqium at the Dept. of Astronomy and Astrophysics, University of Toronto, Sept. 29 (via Zoom). He took part in the following online working meetings in 2021: a Simons Observatory collaboration meeting, 12–16 July, and an Atacama Comsoloty Telescope collaboration meeting, 27–30 July.

Appointments to committees and boards

CONSOLMAGNO continued on the Science Advisory Board of the SETI Institute. With the unfortunate collapse of the Arecibo mian antenna in December 2020, his work on the Science Management Advisory Committee for the Arecibo Observatory has been put on hold.

FRANCL-DONNAY served on the board of the Institute for Religion and Science; was Chair of the Board, Open Chemistry Collaborative in Diversity Equity (OXIDE); Chair, Parish Council of Our Mother of Good Counsel Parish; and served on the Graduate Alumnae Association board for the University of California, Irvine.

GRANEY is a founding member of the "Faith and Science Discussion Group" of Archbishop Joseph E. Kurtz of the Archdiocese of Louisville, Kentucky (USA). The Archdiocese celebrated its first "Gold Mass" for scientists, science educators, and science students on 3 November 2021 at Holy Family Church—an outgrowth of the science group's work. The celebrant was Archbishop Kurtz. A reception followed, with dinner provided by the Louisville Section of the American Chemical Society (ACS). Geoscientist Dr. Kate Bulinksi of Bellarmine University (Louisville) gave an address ("Faith and Science: Compatible and Complementary"), with responses by GRANEY, by Deacon Ned Berghausen of Assumption High School (Louisville), and by Fr. Pat Dolan of the Archdiocese and the ACS.

HINCKS continues as vice-president of the Toronto Chapter of the Society of Catholic Scientists. In 2021 he was appointed as a literary trustee of the Estate of Bernard Lonergan. He also served on some committees in the Dept. of Astronomy & Astrophysics, University of Toronto.

Awards and distinctions

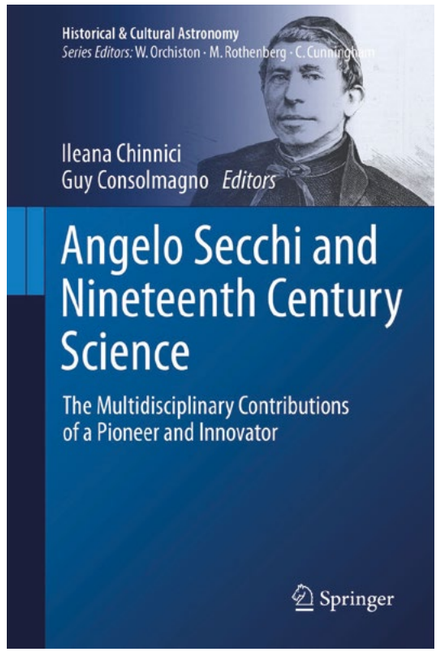
HELLER received "The Man of the Word Award" at the Szczebrzeszyn. Festival of the Polish Language. Szczebrzeszyn is a town in north-eastern Poland. Its name is especially difficult to pronounce, even for Poles. Every year, the Festival of the Polish Language is held in Szczebrzeszyn and the award for literary Polish is given.

Gold Mass for Science, 3 November 2021, Archdiocese of Louisville (Kentucky, USA), Holy Family Church; Archbishop Joseph E. Kurtz, celebrant.

Publications

A reduction in time spent traveling for half of the year has meant more time for research and an increase in the output of books, articles and papers from conference proceedings. This chapter is an overview of the Vatican Observatory staff and scholars' contribution to scientific publications in 2021.

BOOKS



"This volume provides English-language coverage of a vital figure in 19th century Italian and international science and astronomy, collecting together reviews from historians, scientists and scholars representing the multiple disciplines where Secchi made significant contributions during his remarkable career.

It analyzes both his famous and lesser known pioneering efforts with equal vigor, providing a well-rounded narrative of his life's work, as well as his role as a Jesuit priest in Rome during the turbulent years of the mid-19th century."

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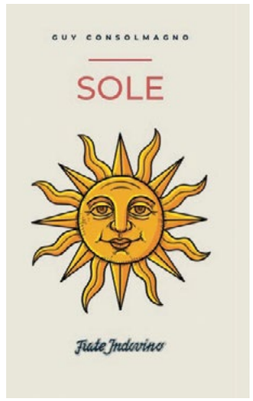
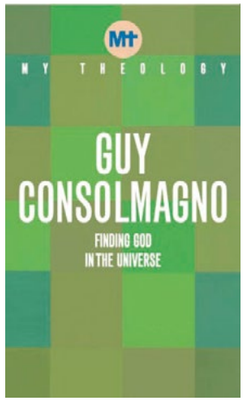
CONSOLMAGNO, G. J. (2021). *Sole*. Perugia: Edizioni Frate Indovino. 160 pp.

CONSOLMAGNO, G. J. (2021). *My Theology: Finding God in the Universe*. London: Darton, Longman and Todd. 87 pp.





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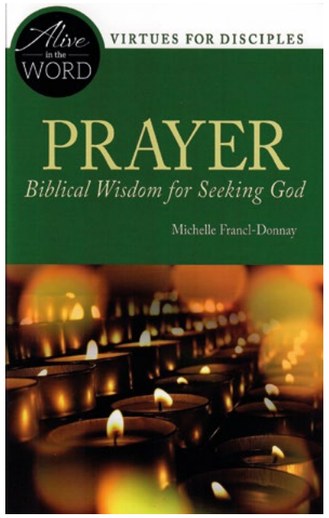

Brożek, B., HELLER, M., Stelmach, J., (2021). *Szkice z filozofii głupoty* (Essays on the Philosophy of Stupidity), CCPress, Kraków 2021, in Polish.

HELLER, M. (2021). *Wierzę, aby rozumieć* (I Believe to Understand), Interview conducted by W. Bonowicz, B. Brożek and Z Liana, second extended edition, Znak–CCPress, Kraków, in Polish.

HELLER, M. (2021). *Czy fizyka jest nauką humanistyczną?* (Is Physics a Humanistic Science? (in Braille), Altix, (8 volumes), in Polish.

HELLER, M. (2021). *Bóg i nauka* (God and Science) (in Braille) Altix (7 volumes), in Polish.

"I am very glad that these two books could be published in Braille. To share some light with people who cannot see is both a privilege and pleasure."- HELLER

HELLER, M. (2021). *Gdy rozerwą się więzy czasu…, Kazania krótkie* (When the Bonds of Time are Broken …, Short Sermons), CCPress, Kraków, in Polish.

HELLER, M. (2021). *Nieskończenie wiele Wszechświatów Od Einsteina do nieskończoności* (Infinitely Many Universes. From Einstein to Infinity), CCPress, Kraków, in Polish.

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ACADEMIC PUBLICATIONS

BOYLE

BOYLE, R. P., JANUSZ, R., Kazlauskas, A., Straižys, V., Zdanavičius, J., Raudeliūnas, S., Maskoliūnas, M., Macijauskas, M., Čepas, V., Semionov, D. Černis, K. (2021). Interstellar Extinction in the Direction of the Open Cluster King 7 and the New Parameters of the Cluster. *American Astronomical Society Meeting* #237, Abstract #150.10

Dulaimi, S., Fitzgerald, K., BOYLE, R. P., Golden, A., Butler, R. F. (2021). The Light Curve Fitter: A novel application for deconvolving two superimposed sinusoidal waves developed using the Agile Software Development Lifecycle. *The 20.5th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (CS20.5)*, March 2-4, 2021. *http://coolstars20.cfa.harvard.edu/cs20half*, id.100

KIKWAYA ELUO, J-B., Hergenrother, C., BOYLE, R., GABOR, P. (2021). Narrowing Down the Physical Characteristics of Optical Fast Rotating NEOs from Spectrophotometry. *AAS Division of Planetary Science meeting* #53, Abstract #306.09

Lin, C-L. et al. [19 authors including BOYLE, R., and GABOR, P.] (2021). EDEN: Flare Activity of the Nearby Exoplanet-hosting M Dwarf Wolf 359 Based on K2 and EDEN Light Curves. *The Astronomical Journal*, 162, id. 11

Soam, A., Andersson, B. -G., Straižys, V., Caputo, M., Kazlauskas, A., BOYLE, R. P., JANUSZ, R., Zdanavičius, J., Acosta-Pulido, J. A. (2021). Interstellar Extinction, Polarization, and Grain Alignment in the Sh 2-185 (IC 59 and IC 63) Region. *The Astronomical Journal*, 161, id. 149

Straižys, V., Kazlauskas, A., BOYLE, R. P., JANUSZ, R., Zdanavičius, J., Raudeliūnas, S., Černis, K., Maskoliūnas, M., Macijauskas, M., Čepas, V., Semionov, D. (2021). Interstellar Extinction in the Direction of the Open Cluster King 7 and New Parameters of the Cluster. *The Astronomical Journal*, 162, 224

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Brown, D. A. (2021). Forward. In Laracy, J. R., *Theology and Science in the Thought of Ian Barbour: A Thomastic Evaluation for the Catholic Doctrine of Creation*. Peter Lang, New York. 326 pp.

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Carotenuto, M., CHINNICI, I., and Randazzo, D. (2019). Astronomical collections in Observatories: Promoting preventive conservation. *Proceedings of the International Astronomical Union*, 15 (S367), 505-507

CHINNICI I. and Randazzo, D. (2021). Angelo Secchi: In the Footsteps of a Jesuit Scientist (Sicily and Calabria, 1875). In *Atti del XL Convegno annuale SISFA – 2020*. (Bevilacqua, F. and Gambaro. I. eds) Pisa University Press: Pisa. pp. 101-112

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CONSOLMAGNO, G. J. (2021). Introduction to *Angelo Secchi and Nineteenth Century Science, The Multidisciplinary Contributions of a Pioneer and Innovator.* (Chinnici I. and CONSOLMAGNO, G., eds.) Springer Nature: Cham, Switzerland. xiii-xiiv

CONSOLMAGNO, G. J. (2021). Box of joys. *The Tablet*, 275, January 9, 32

CONSOLMAGNO, G. J. (2021). Stellar candidates. *The Tablet*, 275, February 13, 32

CONSOLMAGNO, G. J. (2021). Starstruck by Mars. *The Tablet*, 275, March 13, 36

CONSOLMAGNO, G. J. (2021). Engineering the truth. *The Tablet*, 275, April 10, 31.

CONSOLMAGNO, G. J. (2021). Walking with coincidence. *The Tablet*, 275, May 8, 32

CONSOLMAGNO, G. J. (2021). Backwards thinking. *The Tablet*, 275, June 5, 32

CONSOLMAGNO, G. J. (2021). Venus rising. *The Tablet*, 275, July 3, 31

CONSOLMAGNO, G. J. (2021). Gateways to the stars. *The Tablet*, 275, July 31, 32

CONSOLMAGNO, G. J. (2021). One small step… *The Tablet*, 275, September 4, 32

CONSOLMAGNO, G. J. (2021). Soul maintenance. *The Tablet*, 275, October 2, 31

CONSOLMAGNO, G. J. (2021). Great gig in the sky. *The Tablet*, 275, November 6, 30

CONSOLMAGNO, G. J. (2021). Reality is complicated. *The Tablet*, 275, December 4, 32

CONSOLMAGNO, G. J. (2021). Unexpected paths. *Give Us This Day*, April, 151

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CONSOLMAGNO, G. J. (2021). The peaceful village. In *Advent Extra 2021*, Redemptorist Press

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Karmo, T., CORBALLY, C. J., and Gray, R. O. (2021). The Brightest Stars. In *Observer's Handbook 2022*, ed. James S. Edgar. Toronto, Canada: Royal Astron. Soc. Canada. pp.275–283

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CHAPTER EIGHT

Visitors

A second consecutive year of travel restrictions and social distancing measures meant fewer visitors to our headquarters in Castel Gandolfo and facilities in Tucson, Arizona. We look forward to 2022, in the hope we can once again offer a warm welcome to academics, scientists, students and our generous benefactors.

Visitors to the Specola in Rome:

US Ambassador to the Holy See Callista Gingrich and her husband Newt Gingrich.

French ambassador to the Holy See Élisabeth Beton-Delègue.

Dutch Ambassdor to the Holy See Caroline Weijers.

Australian ambassador to the Holy See Melissa Hitchman.

Claudio Gatti and Danilo Babusci and other researchers from the National Laboratories of Frascati (LNF-INFN).

Joachim Karl, who has generously contributed to the meteorite collection, including the cutting of several of the very large meteorite slices that we have on display.

María Gabrielea Navarro, Università di Roma "La Sapienza" & Universidad Andrés Bello (UNAB), and Pontificia Universidad Católica de Chile.

Molly Burhans, Executive director of Goodlands.

Seminarians from the Pontifical North American College (NAC).

The Jesuit Community of the Philosophy Scholasticate of San Saba, Rome.

A group of students from the Netherlands.

A group of professors from the Pontifical Biblicum University.

A group of European formators of the Society of Jesus gathered in Rome at the beginning of November 2021.

Visitors to the Specola in Tucson:

Hsin-I Chang, from the Hydrology and Atmospheric Science department of the University of Arizona; Maria Elena Monzani, of the Kavli Institute, Stanford University, and Katie Steinke of the Vatican Observatory Foundation.

Visits to other institutions for scientific purposes

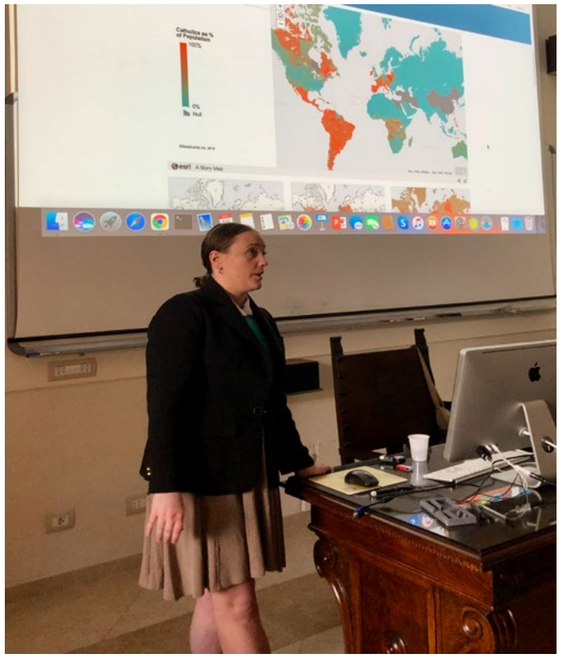
BROWN visited Fordham University in Bronx, NY in order to confer with Fr. John Cunningham, SJ, professor of physics at Fordham.

GABOR took part in the *38th 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 35 professional and amateur astronomers for the event (because of Covid19, fewer than the usual 50). He visited observatories and planetaria in Presov, Roztoky, Kolonica and Kosice (all in Slovakia).

In Kosice, Slovakia, he visited the Technical University, meeting with Kamil Madac and Jozef Zivcak, dean of Mechanical Engineering, and the Institute of Experimental Physics, meeting with Pavol Szabo and Jozef Kacmarcik. He also visited Projectsoft in Hradec Kralove, Czech Republic.

US Ambassador to the Holy See Callista Gingrich and her husband Newt Gingrich with Fr. Paul Mueller.

Australian ambassador to the Holy See Melissa Hitchman.



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