Mem. S.A.It. Vol. 93, 13

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Research and Development activities against the COVID19 pandemic in INAF and surroundings

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On behalf of the INAF research group engaged against the COVID19 pandemic

Received: 28 April 2022; Accepted: 2 May 2022

Abstract. Starting from the critical phases of the COVID19 pandemic in March 2020, the Italian National Institute for Astrophysics (INAF, www.inaf.it) has undertaken specific research and development activities. This program has been carried out in the fight against the virus SARS-COV-2 that involved many other Italian Universities and Research Institutes after the appeal by the Italian Government in March 2020. This paper will shortly review the primary outcomes of the studies led by INAF researchers that have tackled aspects like, e.g., disinfection techniques to neutralize and detect the virus in aerosol, the seasonal evolution of the pandemic as a function of the Sun illumination. Also, new methods for the monitoring of potentially infected people in public areas and environments have been investigated.

Key words. COVID19 Pandemic – SARS-COV-2 virus – Disinfection Technologies – Detection of viruses – Seasonality of pandemics – UV solar illumination - Optical Monitoring technologies

1. Introduction

The SARS-COV-2 coronavirus was first detected in Wuhan, China, at the end of 2019 and then identified as the pathogen causing pneumonia associated with the novel COVID19 disease (Zhu et al. 2019). Afterward, the infection due to COVID-19 was rapidly spread worldwide, becoming a pandemic responsible for dramatic and unforeseeable health and social and economic consequences in the following couple of years. Just now, after two years of hard fighting, the pandemic has slowed down rhythms. This achievement has been obtained after the rapid development of multiple SARS-CoV-2 vaccines and their administration to a large part of the world population. Before that, the containment of the pandemic spread was based on adopting proper rules of conduct (e.g., lockdown and protection masks) and disinfection technologies, particularly to limit the contagions via aerosol.

In the early phase of the COVID19 spread outside China, Italy was the first European country to be dramatically affected by the pandemic, leading to a general lockdown of all activities and social contacts in March 2020. During that difficult moment, the Italian government's Ministry for University and Research (MUR) invited the overall Italian scientific community, including the researchers whose field of interest was not directly related to medicine and biology, to be engaged in contrasting COVID19 diffusion in such an emergency. The MUR appeal was addressed to both Universities and Research Institutes to promote studies, activities, and services supporting the fight against the pandemic (Manfredi 2020).

In such a context, the Italian National Institute for Astrophysics (INAF) decided to participate in this emergency effort, relying on the critical thrust of its President Nichi D'Amico (see the Media INAF news: https://www.media.inaf.it/2020/03/31/astro-anti-covid/). It should be noted that INAF, according to the institutional finalities, besides the activities directly related to astrophysics, also *promotes the exploitation of the results of research carried out or coordinated by its scientific network for productive and social purposes through technology transfer* (INAF 2018).

The first undertaken action was to collect, after a rapid call, the proposals of contributions by members of the INAF community to spin off their know-how in developing methods, technologies, and services valuable to limit the pandemic spread and beneficial to the people hit by the disease.

Therefore, a series of research and development proposals were submitted within the INAF community, presented by many people belonging to different INAF Institutes and research areas (astronomical technologies and instrumentation, planetology, solar physics, high energy astrophysics).

After organizing a central coordination board, the more promising proposals were selected, trying to merge different groups of proposers who submitted ideas in contiguous areas to maximize the momentum. Researchers from other Institutes and Universities, sometimes coming from fields far from astrophysics (including medicine and biology), were also involved in the spirit of proactive multidisciplinary synergies during the emergency. The activities were then focused on the following main themes:

- study of the inactivation of the virus SARS-CoV-2 after the illumination with UV rays;
- study of the COVID19 pandemic seasonal evolution and its relation with the UV Sun illumination;
- development of UV-based disinfection devices and systems for the disinfection of the aerosol and surfaces;
- detection of the virus in the environment with methods and technologies derived from astrophysical instrumentation;
- monitoring of potentially infected people in public areas with optical devices and platforms also used in space science and astronomy.

In addition to the workforce provided by the INAF research and technical people, the activities were supported by some special internal funds immediately provided by INAF for this specific program. It was possible to rapidly test models, perform experiments, and develop prototypes to consolidate the ongoing investigations. The preliminary results were immediately published in preprint documents posted in well-known repository servers, widely utilized by researchers engaged in the fight against the pandemic during the emergency, e.g., medRxiv, bioRxiv, engrXiv, Astro-ph, epiprev. After consolidating the results, several papers have been published in authoritative international multidisciplinary journals in open-source format. In this way, it was possible to rapidly distribute the information from our investigations.

This approach has been appreciated by many scientists and industries that used and quoted our results for other applications and studies during the emergency. We also deposited several patents on the developed methods, with the main scope of preserving the inventions from aggressive industrial speculations. In the following sections, we give a short report on the activities carried out in different investigation areas.

2. Study of the inactivation power of the SARS-Cov-2 virus by UV illumination

This study was undertaken as a joint effort of the astrophysicists of the Brera Astronomical

Observatory - INAF and the biologists and medical doctors of the University Statale of Milano. The researchers of this relatively unusual team put together their different know-how to study the inactivation of the SARS-COV2 virus exposed to UV light at several wavelengths in the so-called UV-C, UV-B, and UV-A spectral bands (100 - 280 nm, 280 -315, 315 - 400 nm, respectively). The early investigation phase started just in March 2020 and focused on analyzing UV-C light's efficiency to inactivate the proliferation of the SARS-COV2. To this end, it was possible to use virus samples directly developed at the University of Milano. The virus for research in the Milano labs was already available, thanks to an agreement with the Spallanzani Institute of Roma, where the SARS-COV2 virus was first detected and separated in Italy. The experiment was carried out with a device based on a mercury lamp at 253 nm developed at the INAF labs. The virucidal property of the UV-C artificial light it is well known and discovered decades ago (Kovalsky 2010), (Reed 2010). Still, different viruses present different behaviors, and it was not clear what dose should have been given to achieve adequate disinfection of the SARS-COV-2 virus suspended in an aerosol. After our experiments, it was possible to show that at a virus density comparable to that observed in SARS-CoV-2 infection, a low UV-C dose of just 3.7 mJ/cm2 was sufficient to achieve a more than 3-log inactivation without any sign of viral replication. The research was fundamental because it demonstrated the high efficacy of UV-C artificial light in rendering the virus inactive. The results were immediately reported in a preprint at the beginning of June 2020 (Biasin et al. 2020). A paper was submitted to Scientific Reports and then published (Biasin et al. 2021), receiving a very high number of downloads (almost 18000 for the full-paper preprint and 19,830 article downloads in 2021 after the publication on Scientific Reports, placing it as one of the top 100 downloaded microbiology papers for the journal in 2021). The number of citation is also very high, as it has been beneficial for the design and implementation of artificial UV-C light system for the safe management of the air indoors. This research has had widespread coverage in both national and international media.

The research then continued performing an in-depth analysis of the virucidal effect of discrete wavelengths: UV-C (278 nm), UV-B (308 nm), UV-A (366 nm), and violet (405 nm) on SARS-CoV2. To this end, a new device was used based on LEDs developed for the scope with the support of De Sisti Lighting (ILT Italy s.r.l., Rome, Italy). Using a highly infectious titer of SARS-CoV-2, we observed that the violet light dose resulting in a 2-log viral inactivation is only 10^4 times less efficient than UV-C light (Biasin et al. 2022) (to be compared to a factor 10^6 typical for bacteria and DNA based viruses). Surprisingly, comparing the UV action spectrum on SARS-CoV-2 to previous results obtained on other pathogens suggests that RNA viruses (like SARS-COV-2 and influenza) might be susceptible to long UV wavelengths. Our data extend previous results showing that SARS-CoV-2 is highly vulnerable to UV light. They can explain the reduced incidence of SARS-CoV-2 infection in the summer season (see next section).

3. The seasonal behavior of the COVID19 pandemic and its dependence on the UV-B UV-C solar illumination

This research concerned the seasonal moderation of viral diseases transmitted by air (and therefore also Covid19) through the UV B and A rays emitted by the Sun, according to the idea firstly suggested by (Lytle and Sagripanti 2005). The study was carried out by applying the inactivation effect of solar UV light to theoretical contagion models to evaluate the possible influence on seasonality (based primarily on solar illumination data derived from satellite measurements). We greatly benefited from the data on the UV-B and UV-A inactivation of SARS-COV-2 directly measured by INAF and the University of Milano.

According to our measurements and other data collected from literature, single-stranded RNA viruses like SARS-COV-2 and influenza, with an apparent seasonal epidemiological behavior, seem much more prone (up to a factor of 1000) to inactivation at UV-A rays produced by our Sun and that copiously reach the Earth's surface than bacteria and DNA based viruses. Combining our measurements of the action spectrum of Covid-19 in response to UV light, Solar irradiation measurements on Earth during the SARS-CoV-2 pandemics, worldwide recorded Covid-19 mortality data, and a "Solar-Pump" diffusive model of epidemics developed by INAF, we have shown that the Solar radiation that reaches temperate regions of the Earth at noon during summers, is sufficient to inactivate 63 % of virions in typical aerosol concentrations in less than 2 min. We have then inferred that the seasonal behavior of the SARS-Cov-2 outbreak, evident, e.g., from the mortality time series (with temperate regions showing clear seasonal trends and equatorial regions suffering, on average, systematically lower mortality), can be well explained in terms of the different UV-B/A Solar fluxes on other Earth's locations at different times of the year (Nicastro et al. 2020), (Nicastro et al. 2021). Moreover, these findings suggest that Solar UV-B/A illumination plays a crucial role in implementing proper strategies for the confinement of the epidemics. INAF researchers now carry out this research with direct onground measures of the UV illumination at different latitudes and locations in Italy with radiometric spectro-photometers. This campaign will allow us to perform a better calibration of the Solar illumination data measured by satellites.

4. Development of UVGI Sanitization systems

Another branch where INAF researchers have been very active has been the direct development of methods and systems based on UVGI (Ultra-Violet Germicidal Irradiation") for the disinfection of the air. The UVGI approach is an efficient technique for the inactivation of pathogenic microorganisms (Kovalsky 2010), known since a few decades but not yet very diffuse in Europe (particularly in Italy). The absorption of UV-C radiation (between 200 and 280 nm) by nucleic acids caused a modification of the chemical bonds with consequent inactivation of the replication processes. As seen in the previous section, based on the measurements performed by INAF and the University of Milano, the mechanism is particularly efficient in the inactivation of the SARS-COV-2 virus. The INAF activities on the development of UVGI systems started in March 2020 (and are still ongoing). Part of the work was devoted to making optical simulations with ray-tracing programs and fluid-dynamic studies to optimize device performance (Lombini et al. 2021-a), (Lombini et al. 2021-b); in this respect, the previous know-how matured in the design of optical systems for astronomical adaptive optics has been very useful. Thanks to this approach, it was possible to conceive innovative systems (that have been patented (Lombini et al 2021-c)), proper calibration, and verification methods. Also, INAF supported several national and international industries and private designers engaged in developing new commercial systems for the purification of the air and disinfection of surfaces. A first filter device, based on a cylindrical UV-C reflecting cavity illuminated by LEDs, was designed for the disinfection of the air expelled in the breath by patients supported by artificial respirators. The system is being prototyped, in a program funded by the Emilia Romagna Region, by INAF in collaboration with the Intersurgical s.p.a firm and Tecnopolo Mirandola. Another application regarded the design for an effective pathogens inactivation in air ducts through UVC light. A device for disinfecting a fluid flow in a conduit using UV-C radiation has also been conceived. In this case, the portion of the duct where the UV-C illumination sources are installed is not only coated with a UV-C reflecting material. It is also curved along the meridional direction to amplify the number of reflections and interactions with the microorganisms. A breadboard of the concept is now being realized by INAF, in collaboration with the CSTM Brescia. Moreover, a device for air sanitization in closed rooms where it is impossible to introduce external clean air using ducts has been designed. The breadboard has been developed in collaboration with the NVKDESIGN firm (Macchi et al. 2022).

5. Systems for the detection of the virus in the environment

Another branch of the activities carried out by INAF regarded the development of devices and methods for rapidly identifying the SARS-COV-2 presence in the air (e.g., in a closed room). It is known from the literature that a cloud is generated as a result of exhalations, sneezing, and coughing of turbulent gas carrying a swarm of droplets containing quantities of SARS-CoV-2 sufficient to transmit the infection, which can travel distances of about 7-8 meters and remain in the air up to about 3 hours, thus contributing to the spread of the virus. At the same time, it can stay in ventilation systems and aeration systems. It is also essential to show up on time for the virus in patients potentially affected by COVID19, for example, by directly sampling the air breathed.

In this respect, it has been conceived and is under the breadboarding the SAFAIR (Spaceborne Automatic Facility for Environment Analysis with Integrated Rt-pcr) system (Esposito et al. 2021). This device is based on technologies for astronomical space experiments developed by INAF (particularly at the Observatories of Capodimonte and Arcetri) and by Italian Universities (Roma La Sapienza, Bologna, and Politecnico of Milano). It aims to efficiently and automatically sample the aerosol present in closed places (e.g., hospital rooms, supermarkets, offices, lifts, vehicles, transport cabins, schools, university classrooms, etc.) and reveal the presence of the SARS-CoV-2 virus in real-time in the air. SAFAIR would also allow us to search for the virus in the aerosol produced by the patient's breathing and its possible presence in the aeration systems. It relies on three main modules mounted in series to perform the sampling and analysis of the air. Module 1 is based on the MicroMED instrument developed for the space mission ExoMars (Mongelluzzo et al. 2019); it aspirates the air with high efficiency, captures the aerosol droplets, and then transfers them to the next Module 2. In this stage, the RNA is extracted from the collected biological sample, then moved to Module 3. Here a lab-on-chip device (that was already developed and will also operate aboard a CUBESAT space mission devoted to Astrobiology (Brucato et al. 2021)) performs the amplification and detection of the nucleic acids of the virus. The whole system is autonomous and automatic and does not require the intervention of expert operators. A breadboard of SAFEAIR is being finalized, and it will be tested and calibrated with samples of SARS-COV-2 by summer 2022. Other detection methods for the SARS-COV-2 virus are being studied in the sCOVATO project (Bolli et al. 2022), led by INAF-Arcetri Observatory and including researchers from the Italian National Research Council (CNR) the University of Roma La Sapienza, and the Istituto Superiore di Sanitá (ISS). The project aims to develop a rapid, specific, and low-cost diagnostic methodology for detecting viral infection in material extracted from pharyngeal swabs. To this end, two distinct methods to detect the virus antigens in biological material using a spectral multi-frequency approach are used, i.e., in the microwave and visible wavelengths, respectively. Unlike the current system based on the polymerase chain reaction (PCR), in the sCOVATO approach, the presence of the virus in biological material is directly searched for through a spectrometric analysis using electromagnetic fields with specific characteristics. To this end, two different electromagnetic spectral bands, the radio and visible band, are considered. Using differential measures, the absence/presence of pathogens coronavirus is evaluated by observing in the radio band the spectral trend of the dielectric parameters of the biological sample, followed by the analysis in the visible band of the fluorescence signal emitted. Preliminary tests have been performed, and promising results have been obtained (see the paper in this proceedings).

6. Develpment of systems for the monitoring of groups and detection of feverish persons

INAF groups performed an effort also to develop valuable systems for the monitoring of people during the pandemic.

At INAF Osservatorio Astronomico di Palermo an aerostatic balloon-born technology for video surveillance for public safety has been developed that can be used fruitfully used to protect large areas by identifying gatherings of people outdoors (Todaro et al. 2022). The platform has been designed to continuously monitor large areas of the territory for long periods. It uses a specific tethered balloon equipped with a high-resolution camera with high magnification optical zoom and a thermal imaging camera (IR).

Complementary instrumentation is represented by a panoramic environmental monitoring system developed by INAF Osservatorio Astronomico di Padova researchers (Pernechele et al. 2022). The concept's core is a novel bifocal panoramic lens that was initially designed and realized as a star-tracker for mini and micro-satellites. Some modifications, particularly on the software for the correct interpretation of the images, can be used as an environment monitoring system in dangerous areas during the pandemic phase. The system records a field of view (FOV) of 360° in azimuth, +60°/-40° in elevation (scenic area), and, simultaneously, an enlarged part of it (with a 3x magnification factor). A prototype has been developed, and tests are being performed.

7. Conclusions

This article reviews the activities to contrast the COVID19 pandemic carried out by INAF researchers since the early stages of the emergency in Italy (March 2020). The research covered various areas and involved researchers from other institutes and universities. The studies carried out by INAF and the University of Milan have been of great significance in showing that the SAR-COV-2 virus is particularly susceptible to inactivation by irradiation with ultraviolet rays. This has stimulated the design of systems and methods for neutralizing the virus in aerosols by irradiation with artificial sources with emission in the UV-C band. Furthermore, these results suggested that the observed seasonal trend of the COVID19 pandemic may be related precisely to solar lighting and natural radiation with UV-B and UV-A rays. Other interesting researches concern fast virus detection systems using technological approaches already used by INAF in space and astronomy. Further developments have dealt with tools for monitoring groups and people potentially affected by the virus with adopting technologies derived from astronomical fields.

Acknowledgements. INAF's research, to contrast the COVID19, began thanks to the invaluable and untiring support of INAF President Nichi D'Amico. Nichi D'Amico was an outstanding scientist who provided continuous support and valuable guidance as INAF President; he passed away in September 2020, but his vision is still guiding us. We are very grateful to Prof. Clerici, M. Biasin, and D. Trabattoni from the University of Milan for trusting in collaborating with INAF. Thanks to Prof L. Mazzarella, Politecnico di Milano) for many interesting discussions. The De Sisti Lighting firm (ILT Italy s.r.l., Rome, Italy) provided excellent technical support by developing a particular device for performing the LED UV illumination of the virus samples.

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