Physics in the Scientific Response to COVID-19

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Introduction

The focus of the project was on analysis of the involvement of physics in the scientific response to the COVID-19 pandemic. The methodology of the authors was to take a systems perspective on the pandemic, and to perform literature reviews across the primary areas of involvement of physics research. Current techniques based on research in physics, as well as prospective future techniques, were studied qualitatively and quantitatively using the aforementioned publications, sources of pandemic, and epidemiological simulations.

Detection: Cryo-EM and Fluorescent DNA

X-ray crystallography and cryo-electron microscopy have helped virologists determine which parts of the virus are best suited targets for antiviral attack. The interactions between x-rays or electrons and the sample have been recorded and used to produce thousands of images of the structure of the sample, all at different orientations. Fourier analysis and signal processing techniques are used to generate 3D maps of the sample.

In response to the testing demands of COVID-19, a team at the University of Oxford developed a novel detection method using fluorescent DNA strands to label virus particles, which makes them bright enough to be detected by a computer. The group identified non-specific viruses in fewer than 5 minutes, and detected SARS-CoV-2 from clinical samples with a sensitivity of ~70%.

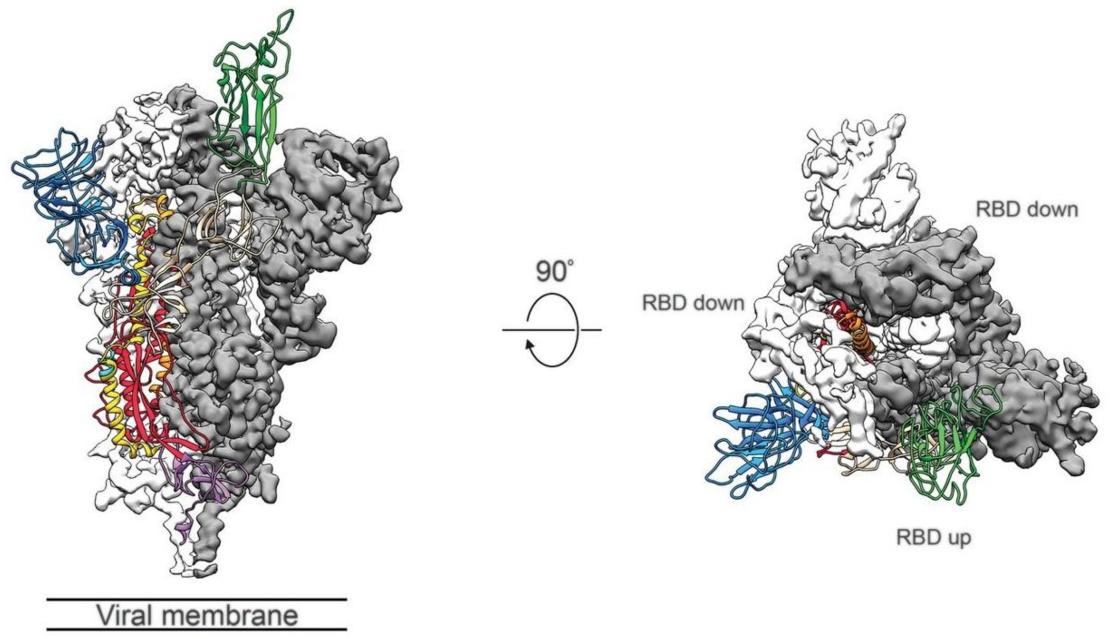

Fig 1. Side and top views of the prefusion structure of the SARS-CoV-2 spike protein obtained using cryo-EM[3].

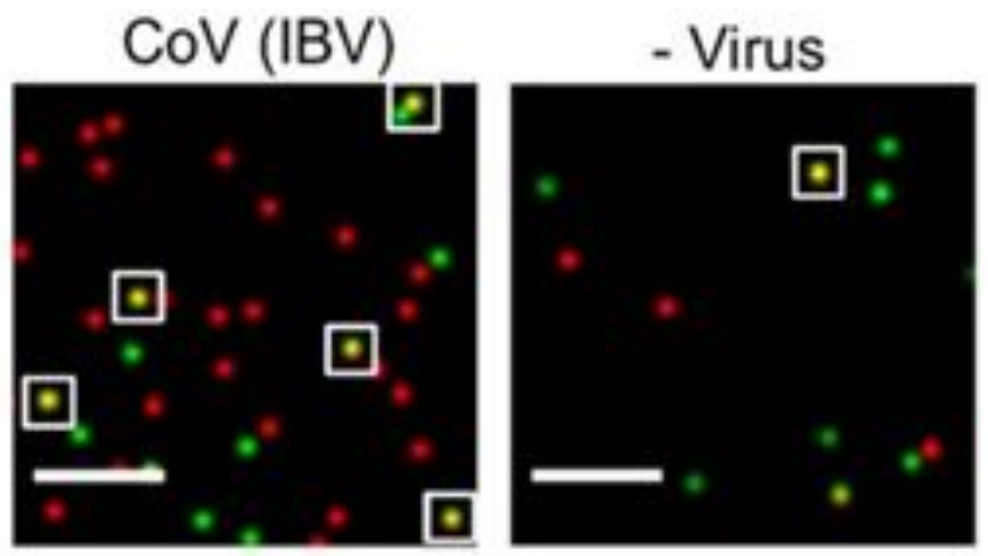

Fig 2. A fluorescent DNA treated sample containing an avian coronavirus (CoV - IBV) (L), and a sample containing no virus (R). White squares indicate particles with both red and green fluorescent DNA present, which are more likely to be viruses [1].

Simulations: Airborne Transmission

The airborne transmission of COVID-19 was modelled as aerosols [2]. Computational methods were used to model the diffusion of aerosols in an office-space.

The dose-response model estimates the quanta of dose required to start an infection. The probability of infection was obtained from the dose-response model:

$$P_I = 1 - e^{-D_q}$$

where $D_q \propto$ number of aerosols gained.

The following interventions were used to minimise the probability of infection: ventilation, far-UVC light and masks. The most effective intervention was the use of 95% efficiency masks with ventilation, with the probability of infection reduced to 0.25%.

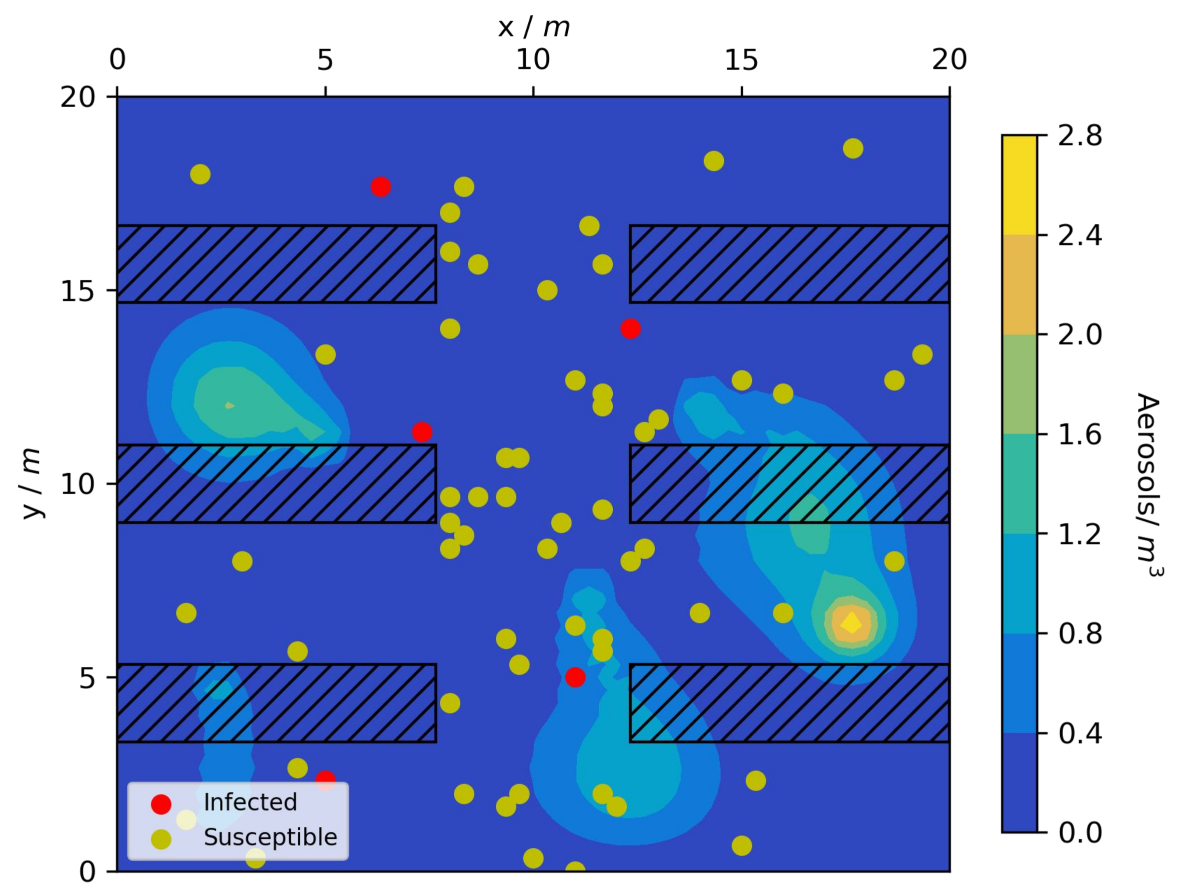

Fig 4. A gradient plot of the concentration of aerosols spread throughout the room with ventilation. With n = 64 individuals, of which 5 infected.

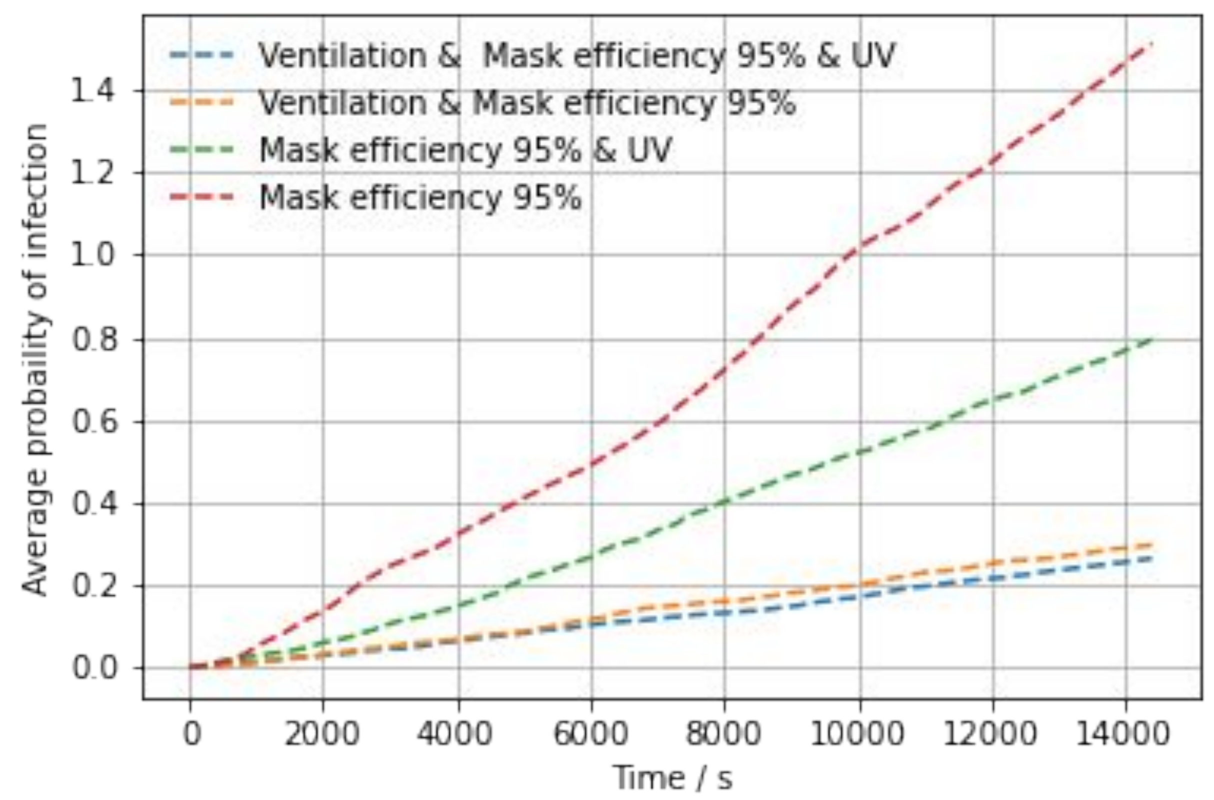

Fig 5. The average probability of infection with 95% efficiency mask, ventilation & far-UVC. A total of n = 64 individuals, of which 5 infected for t = 4 h

Viral Inactivation: UV and ISRS

Inactivation methods, which render viral pathogens non-infectious, have the prospect of contributing to the treatment, containment and eradication of COVID-19 via selective sterilisation of SARS-CoV-2 in patients, disinfection in poorly-ventilated environments, and faster whole inactivated virus (WIV) methods for developing vaccines in response to emerging strains.

The genetic material of SARS-CoV-2 can be damaged directly using far UV-C light, reducing simulated spread, in particular when used with face masks. The hydrogen bonds between viral proteins can also be broken using ultrashort pulsed lasers (USP), which exploit impulsive stimulated Raman scattering (ISRS) and the symmetry of viruses through their characteristic resonance frequency, without risk of cytotoxicity in mammalian cells, as in Table 1.

	Micro-organisms			
	M13	TMV	G-f bacteria	Jurkat T-cell
Threshold power density for inactivation ($\mathrm{MWcm^{-2}}$)	60	250	900	22,000

Table 1. Threshold power density for USP inactivation [5].

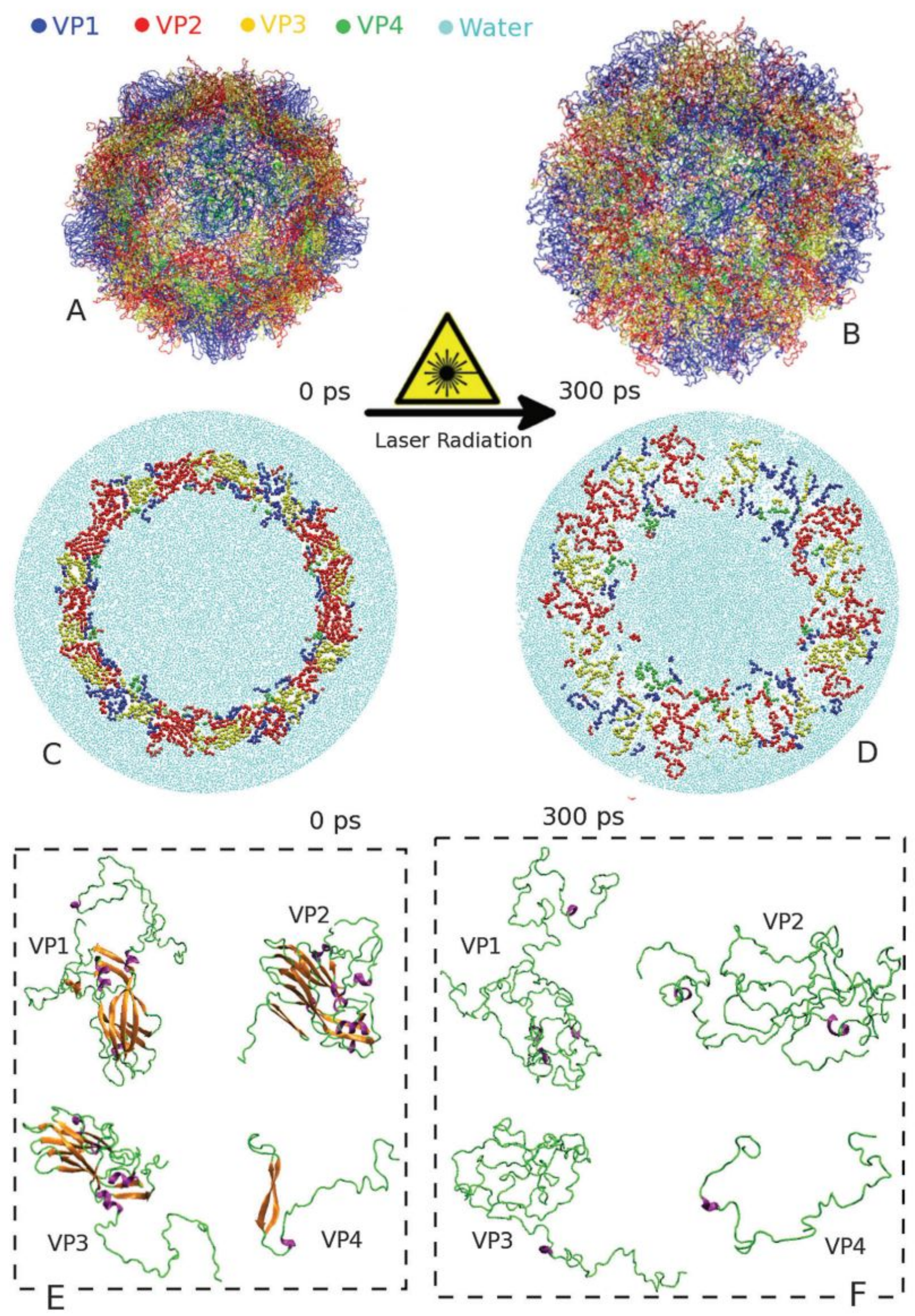

Fig 3. 3D equilibrium structure and cross-section of poliovirus before excitation and after 300 ps of laser-induced dissociation [4].

Masks: Magnetised Microfibers

A typical NIOSH certified N95 respirator mask is made of multiple layers, the inner filtration layer of meltblown microfiber electret polypropylene. Its non-woven structure is effective at capturing submicron particles via Brownian motion and Van der Waals forces, and above 1 micron sized particles via impaction and interception.

The electrostatically charged fibers causes that viral water droplets to be polarised within the electrostatic field, attracted via the Coulombic forces, veered via magnetic induction in motion, and intercepted. Together, this constructs an effective respiratory inoculum capable of filtering 95% of particles.

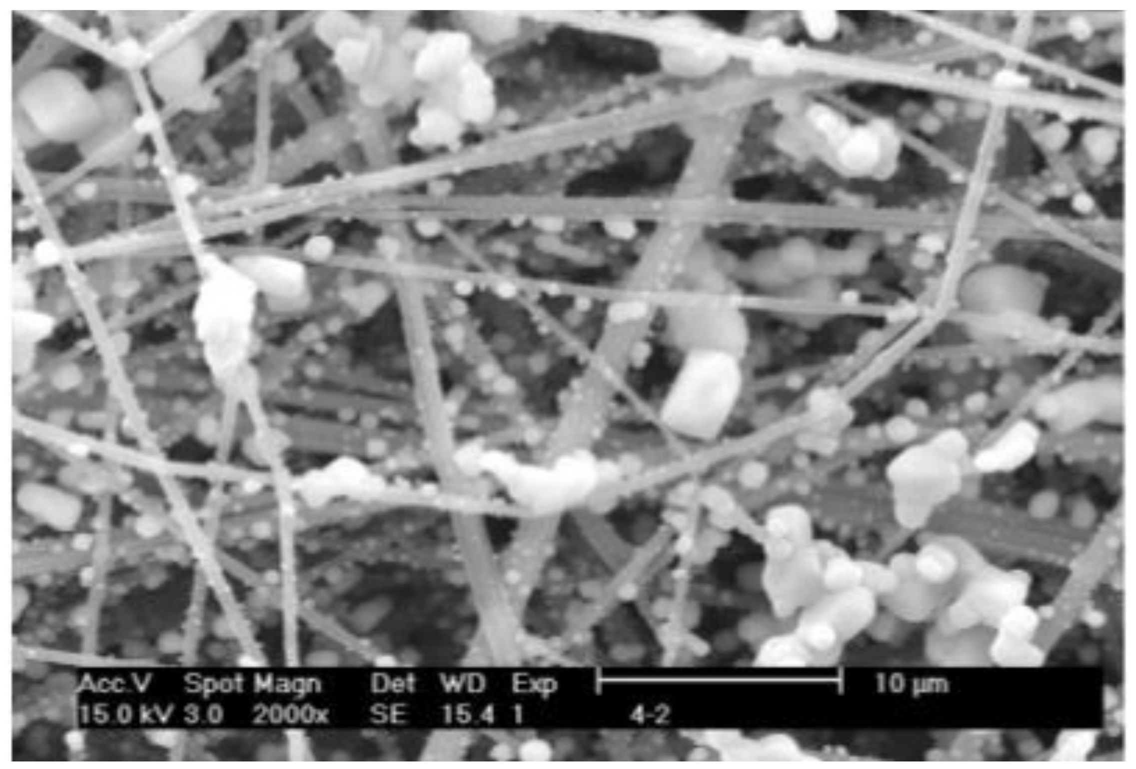

Fig 6. SEM image of a mask's microfibers with captured particles [6].

Conclusion

Current techniques based on research in physics, as well as prospective future techniques, were studied. The simulation compared the performance of containment measures studied and demonstrated that they are most effective at controlling transmission when used in concert with each other. It is hoped that these findings can contribute to devising safer environments, and are a valuable case study in the application of both literature reviews and numerical simulations to the pandemic's challenges, which require a systems perspective.

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