Project Title	Fungal Ice nucleation: Moulding our environment?
University (where student will register)	University of Warwick
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☒ Organisms & Ecosystems ☒ Dynamic Earth ☐
Supervisory team (including institution & email address	**PI: Dr Thomas Whale (Warwick, tom.whale@warwick.ac.uk)** **Co-I: Dr Ester Gaya (Royal Botanic Gardens Kew)** **Prof Matthew Gibson (Warwick, m.i.gibson@warwick.ac.uk)**

Project Highlights:

- Work with Royal Botanic Gardens Kew and the University of Warwick to establish why various fungi cause ice to form in the environment
- Examine the interaction between atmosphere and biosphere and the role of fungi in this relationship
- Work in a truly interdisciplinary environment to develop skills and knowledge in plant science, low temperature science and chemistry.

Overview (including 1 high quality image or figure): *Maximum 350 words*

Small droplets of liquid water can supercool to temperatures as low as -38°C, meaning ice formation in the environment is usually triggered by heterogeneous surfaces such as mineral dusts and biological particles, a process called heterogeneous ice nucleation. Nucleation of ice from supercooled water strongly influences weather and climate by altering the properties of mixed-phase clouds. Numerous biological substances including pollen grains, bacteria and fungi are thought to nucleate ice in the environment, causing strong links between the biosphere and atmosphere. The details of these interactions remain poorly understood (Morris et al., 2014).

Some species of fungi, notably members of the *Fusarium* genus are known to nucleate ice at very warm temperatures (Pouleur et al., 1992), but it is unknown why fungi have evolved this ability. Many ice-nucleating bacteria are plant pathogens and nucleate ice to damage plants in cold temperatures, increasing access to nutrients. Some fungi are also plant pathogens, and their ice nucleation ability may have this function. As such, the potential impact of fungal ice nucleation on crops and the rhizosphere are of substantial interest. Fungi may also nucleate ice to acquire moisture in cold and dry environments, or to help them survive freezing conditions.

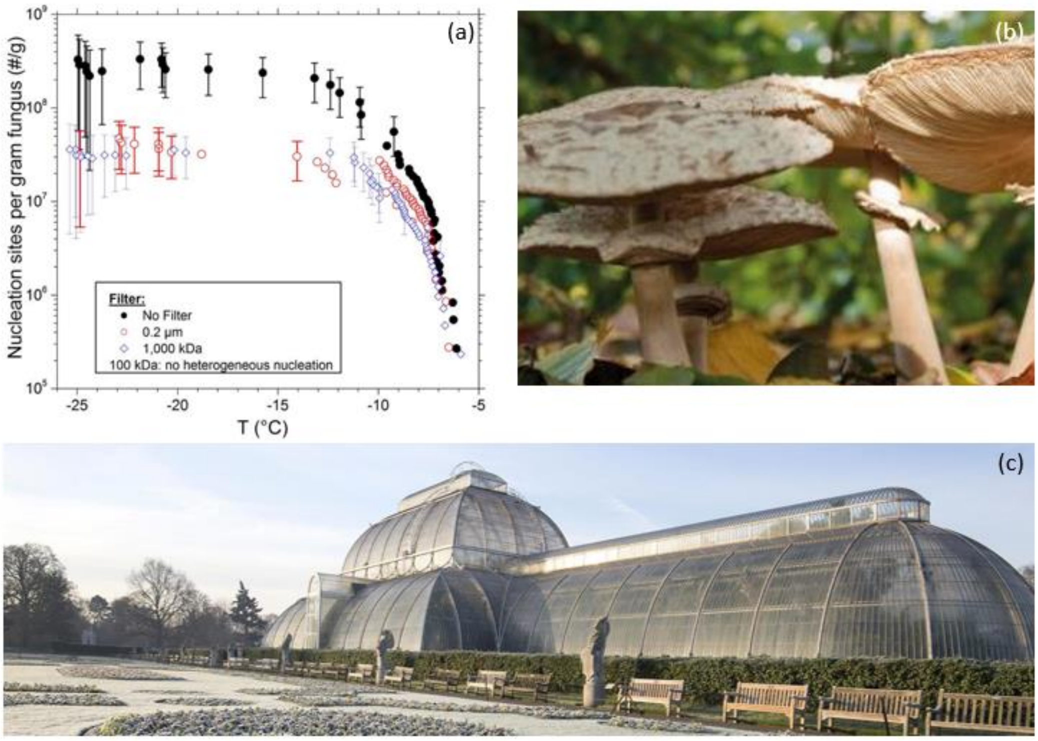

Figure 1: (a) nucleation temperatures of extracts from Fusarium avenaceum *(O'Sullivan et al. 2015)*. (b) Photograph of Chlorophyllum rhacodes at RGB Kew, ice nucleation ability unknown. (c) Photograph of the Palm House at RGB Kew, in snow.

To date, ice nucleation measurements on fungi haven't been performed in a systematic way, and only around 5 fungal genera have been looked at, with just a handful of active species identified, mostly concentrated in the *Fusarium* genus (Kunert et al., 2019). Working between the University of Warwick (UoW) and Royal Botanic Gardens Kew (RGB Kew) the student screen ice nucleation activity across the fungal kingdom using an ecological and phylogenetic framework. We aim to assess the phylogenetic informativeness of this trait and identify potential lineages likely to nucleate ice well. This information will help in understanding the interaction of fungal ice nucleation with plants and the wider environment and allow understanding of the potential role of fungal material in atmospheric ice nucleation.

Methodology:

This project will combine expertise in fungal phylogenetics and ecology at Royal Botanic Gardens (RGB) Kew with expertise in ice science at University of Warwick. The recently funded fungal component of the Plant and Fungal Trees of Life (PAFTOL https://www.kew.org/science/our-science/projects/plant-and-fungal-trees-of-life) project at Kew aims at whole genome sequencing all 8,200 known fungal genera. By testing the diverse fungal specimens selected for PAFTOL using high-throughput ice nucleation measurement techniques a comprehensive picture of the ancestral origin and genetic basis of fungal ice nucleation will be revealed, facilitating improved understanding of 1) the interaction of fungi with climate and biosphere; 2) the biological origin of ice nucleation by fungi, which is typically attributed to heat resistant proteins, but requires further study.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

At the University of Warwick (UoW) students will receive training in ice specific analytical techniques and biomacromolecule characterisation as well as general chemical analytical techniques such as Raman and IR spectroscopy, differential scanning calorimetry and X-ray diffraction, amongst others.

RBG Kew will provide extensive relevant training in plant science. RGB Kew also has particular expertise in science communication with specific training provided and opportunities to write for the RGB Kew website and social media channels and engage with media outlets.

Skills developed in the course of the PhD will be interdisciplinary and relevant to a wide range of fields in industry and academia including atmospheric science, plant science, analytical chemistry and science communication.

Partners and collaboration (including CASE):

Name of L1/L2 Partner (where applicable)	Royal Botanic Gardens Kew
Name of CASE partner (where applicable – project proposal **must** be accompanied by a letter of support from the CASE partner)	

Further information on partners and collaboration (including CASE):

This project will be a partnership between the Chemistry department at UoW and RBG Kew. The student will be flexibly based between the two institutions. At UoW, Dr Whale provides expertise on ice science and ice nucleation measurement and Prof Gibson provides expertise on biomacromolecular science. Dr Gaya and RGB Kew provide expertise on fungal phylogenetics as well as the vital access to a wide range of fungal species. The project can also make use of the presence of Dr Gabriele Sosso at UoW for complementary molecular dynamics simulations of ice formation in biological systems.

Respiratory and Contact Infection Resilience of the Project:

The project is lab based and will require extensive laboratory work. At UoW lab access was largely maintained throughout the pandemic with stringent controls to minimise risk of COVID-19 transmission. It seems likely that this access will be maintained in the event that more stringent COVID-19 regulations are re-enacted. Similarly access to gardens and collections at RGB Kew was possible during the height of the pandemic, if more difficult than in normal times. As such, the project should be able to proceed under most likely conditions, if possibly in a more restricted, less interactive fashion than would be ideal.

Possible timeline:

Year 1 - Q1 and Q2: The student will work in the Whale group at UoW to learn how to perform ice nucleation measurements, while testing the nucleation activity of readily available fungal samples. Some characterisation work on the fungal ice nucleating protein will be performed, both to build familiarity with lab techniques and to establish methods for determining the chemical similarity of fungal ice nucleators across the fungal family tree.

Q3 and Q4 - The student will spend time at RGB Kew, collecting samples of various fungi, and begin to build a database of ice nucleation ability across the fungal family tree. The student will use PAFTOL and other phylogenetic tools to guide this process.

Year 2 - The student will have a partial database of fungal ice nucleation at this point. It is likely that certain species will be thought likely to have strong ability to nucleate ice, due to phylogenetic and ecological analysis. Work will likely focus on establishing how similar the fungal ice nucleating proteins across species is.

Year 3 - Overall, using data on fungal ice nucleation ability together with literature data on the phylogenetic and ecological profiles of the relevant plant species, the student will aim to establish why fungus nucleates ice. Hypotheses will be tested by examining the ice nucleation ability of untested species whose ice nucleation can be predicted from phylogenetic and ecological data.

Further reading:

KUNERT, A. T., PÖHLKER, M. L., TANG, K., KREVERT, C. S., WIEDER, C., SPETH, K. R., HANSON, L. E., MORRIS, C. E., SCHMALE III, D. G., PÖSCHL, U. & FRÖHLICH-NOWOISKY, J. 2019. Macromolecular fungal ice nuclei in Fusarium: effects of physical and chemical processing. *Biogeosciences,* 16**,** 4647-4659.

MORRIS, C. E., CONEN, F., ALEX HUFFMAN, J., PHILLIPS, V., PÖSCHL, U. & SANDS, D. C. 2014. Bioprecipitation: a feedback cycle linking Earth history, ecosystem dynamics and land use through biological ice nucleators in the atmosphere. *Global Change Biology,* 20**,** 341-351.

POULEUR, S., RICHARD, C., MARTIN, J.-G. & ANTOUN, H. 1992. Ice Nucleation Activity in Fusarium acuminatum and Fusarium avenaceum. *Applied and Environmental Microbiology,* 58**,** 2960-2964.

Further details:

Enquiries are very welcome. Please contact Dr Whale at tom.whale@warwick.ac.uk or Dr Gaya e.gaya@kew.org. Further information about RGB Kew is available at (https://www.kew.org/) and further information about the Chemistry department at the University of Warwick is available at (https://warwick.ac.uk/fac/sci/chemistry/).