Polymer coatings for passive radiative cooling obtained by electrospinning: synergy between morphology and chemical composition

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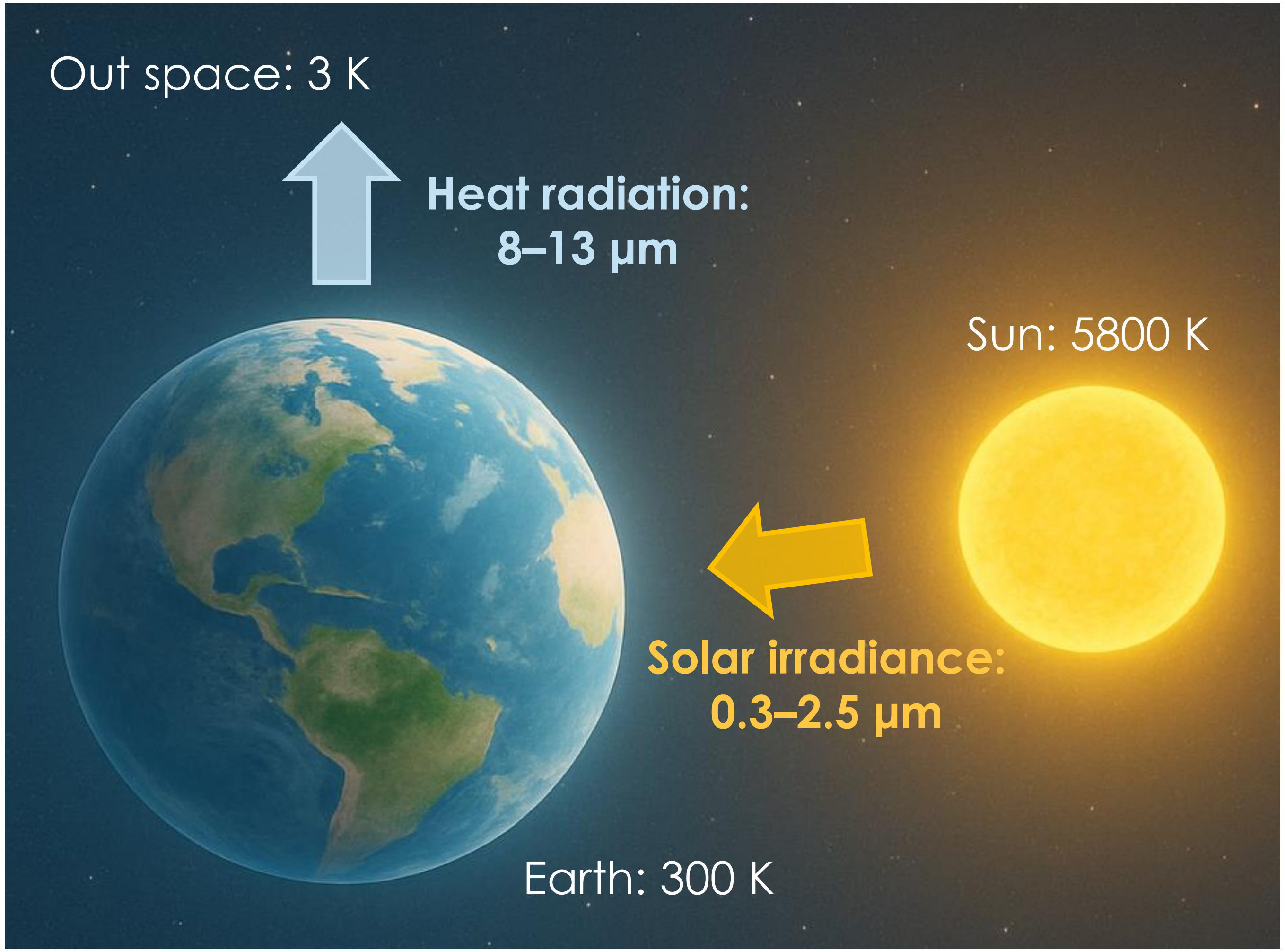
PolyMat research group

INSTM – Politecnico di Torino Research Unit

- New **polymeric materials** and **thermoset composites**
- **Films, electrospun membranes, 3D printing** (stereolithography and Liquid Deposition Modeling)
- **Applications:** coatings, adhesives, packaging, radiative cooling systems, filters, biomedical devices
- **Sustainability**: bio-based polymers/precursors, natural fillers (cellulose), recyclable materials (dynamic polymer networks), photochemistry
- **Composition:** 3 professors, 1 post-doc, 8 PhD students, 2 research fellows

Passive daytime radiative cooling (PDRC)

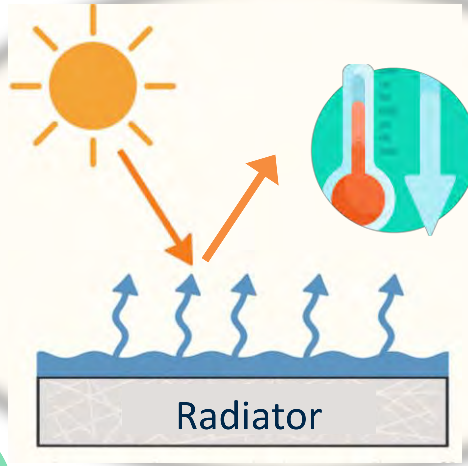


PDRC is a cooling strategy that allows surfaces to stay cooler than the surrounding air during the day, without consuming energy

- Reflection of sunlight in the 0.3–2.5 μm wavelength range
- Emission of infrared thermal radiation through the atmospheric transparency window (ATW, 8–13 μm)
- Absorbance of solar radiation < emission of thermal radiation

D. Zhang *et al.*, Materials 16, 2023
L. Li *et al.*, Advanced Composites and Hybrid Materials 8, 2025

Passive daytime radiative cooling (PDRC)



Environmentally friendly, passive, effective, and **energy-saving** technology

Can be applied to practical applications by placing **radiators** directly on surfaces, or by cooling **heat transfer fluids** (e.g., water)

Promising strategy for **efficient thermal management** (potential cooling applications in buildings)

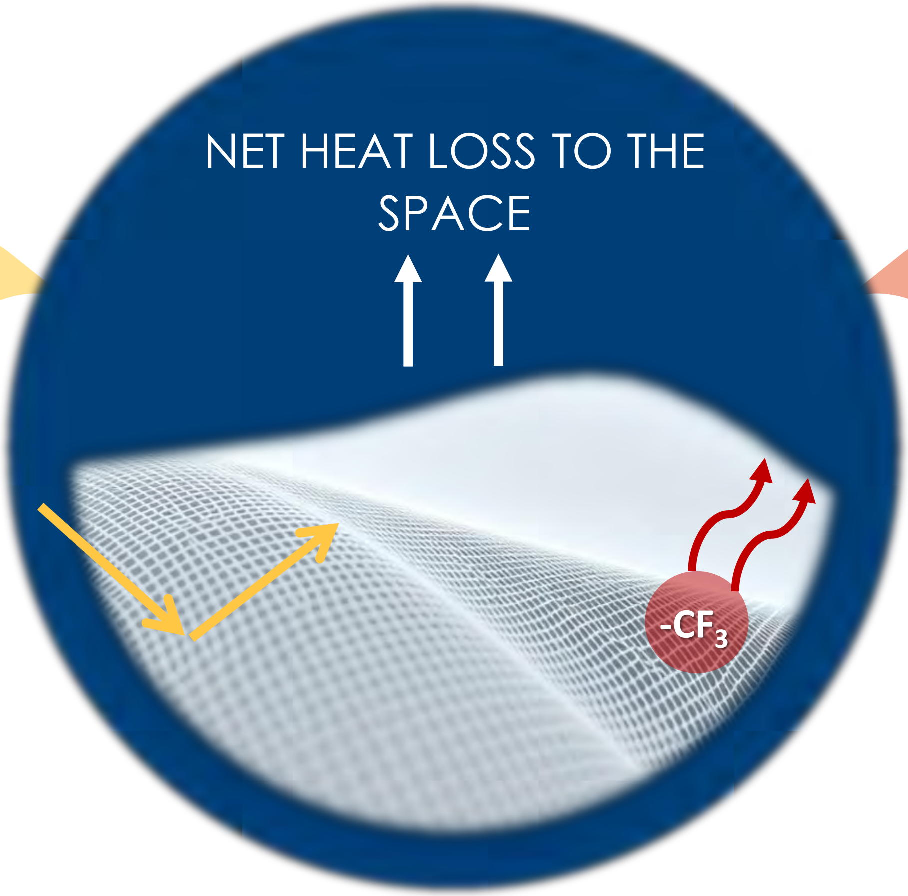
Engineering of **various types of materials and structures** (e.g., multi-layered inorganic materials, polymeric films, metamaterials, smart/switchable materials, biomimetic materials)

S. Wu *et al.*, Advanced Optical Materials 11, 2023
C. Wang *et al.*, Progress in Materials Science 144, 2024

Innovative polymeric coatings for PDRC

Our research focuses on the development of **advanced polymeric coatings** with ultra-high reflectance in the solar spectrum and high emittance in the ATW

Light scattering based on micro- and nano-structures



Selective infrared emission based on bond vibrations

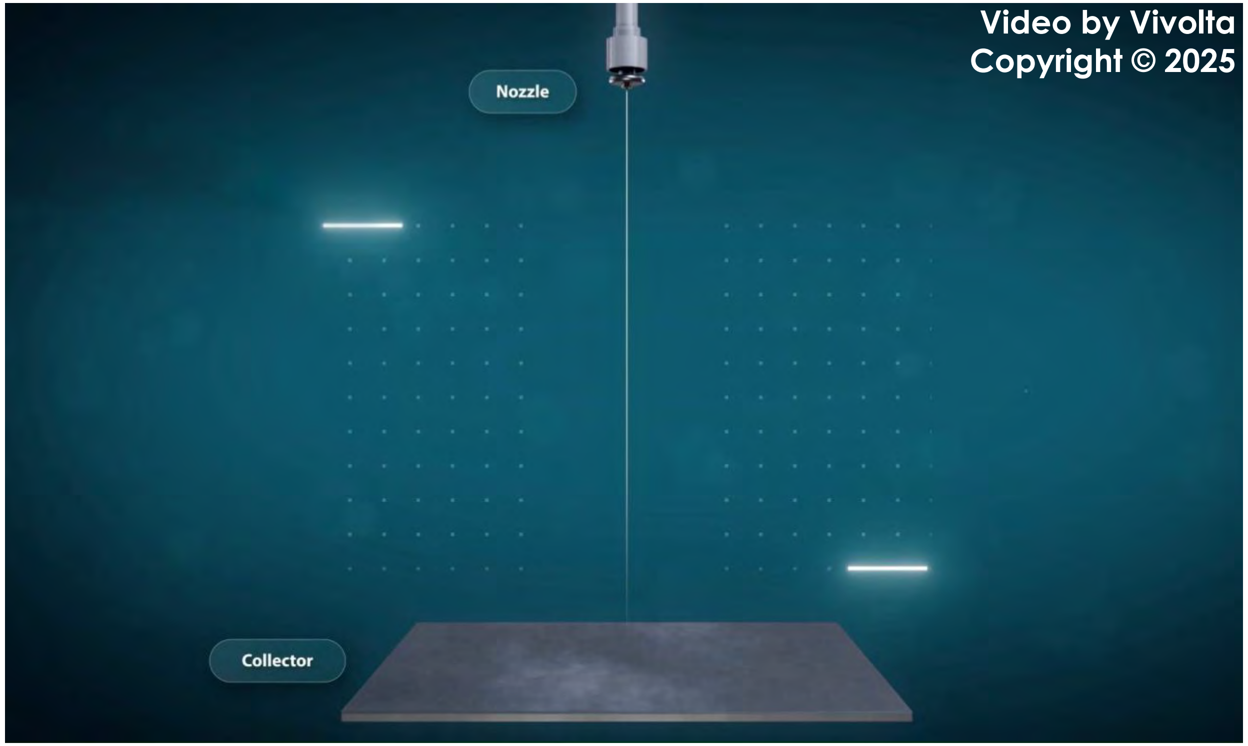
Nanostructured morphology

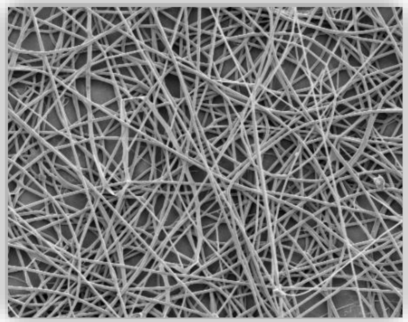
→ Electrospinning

Chemical composition

→ Fluorinated polymers

Electrospinning





Electrospinning is a versatile and promising technology for the mass production of nonwoven nanofibrous materials: polymer fibers are produced by an electrostatically driven jet of a polymer solution, formed by the application of a high voltage

- Possibility to process a large set of polymers, both natural and synthetic
- High porosity, large surface area, tunable optical properties, low cost, ease of processing

J. Xue *et al.*, Chemical Reviews 119, 2019
A. Keirouz, Advanced Materials Technologies 8, 2023
https://www.vivolta.com/our-technology

Electrospinning

- The mat and fibers morphology can be controlled by several parameters

Solution
Molecular weight, concentration, viscosity, electrical conductivity, solvent, surface tension

Processing
Voltage, flow rate, needle-collector distance, needle diameter, shape of the collector

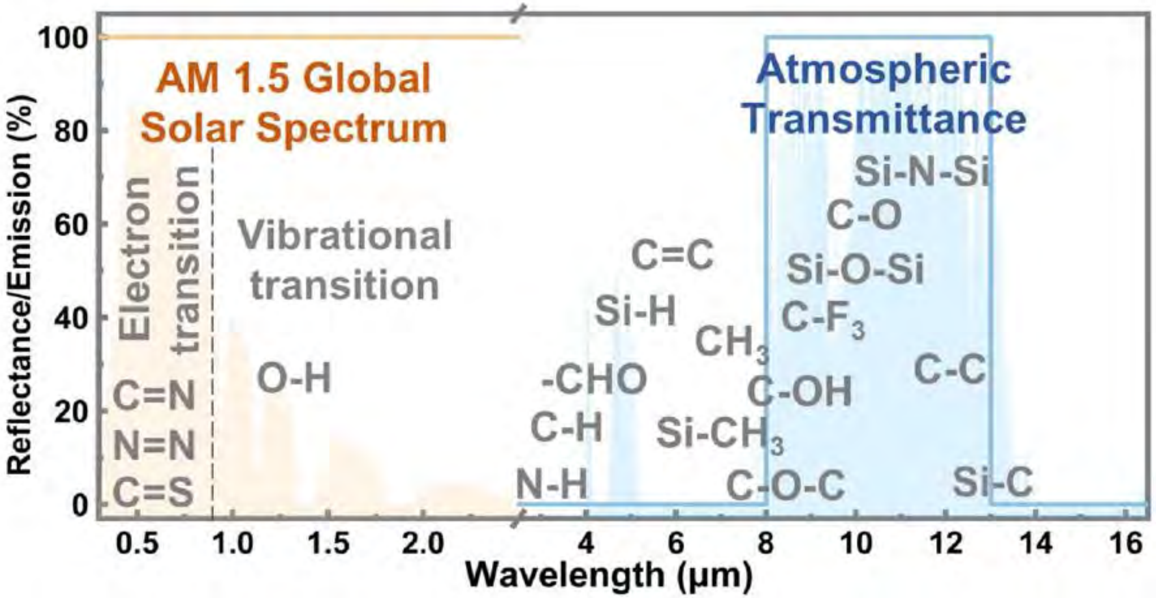
Ambient
Relative humidity, temperature, pressure

- Scalable production (e.g., multi-needle systems, needless systems, or roll-to-roll collectors)

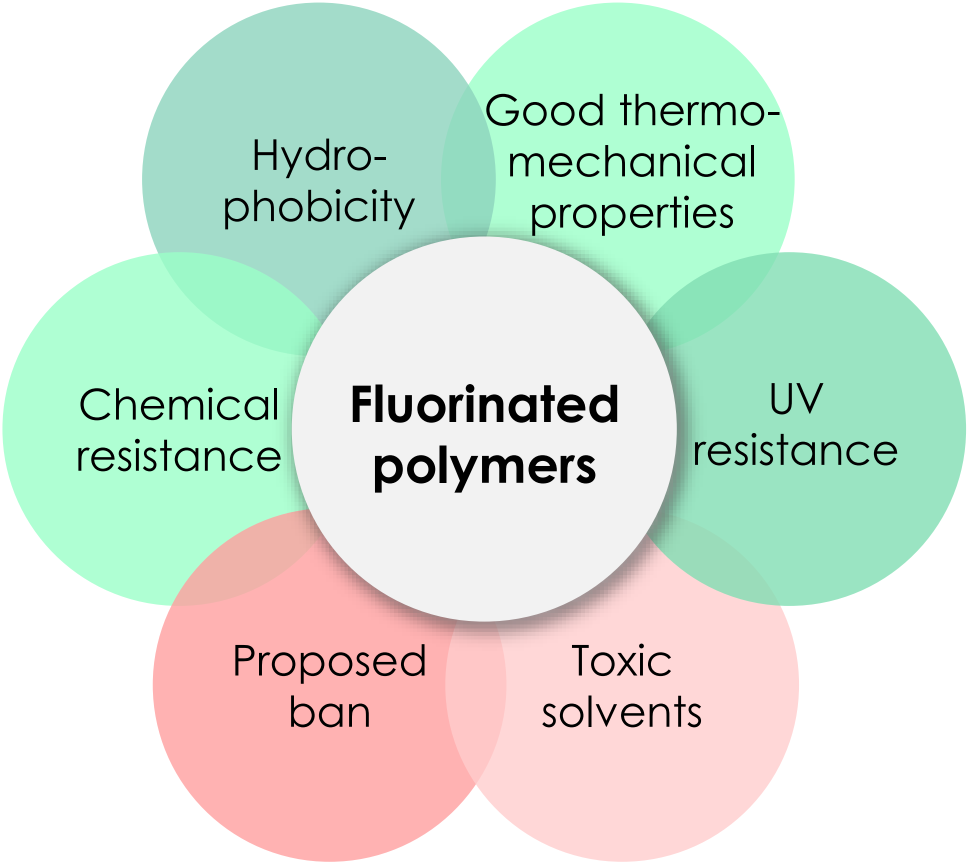
J. Xue *et al.*, Chemical Reviews 119, 2019
A. Keirouz, Advanced Materials Technologies 8, 2023
https://www.vivolta.com/our-technology

Fluoropolymers for PDRC

- Fluorinated functional groups ($-CF_3$) show suitable infrared absorption/emission peaks



A. Aili *et al.*, Materials Today Physics 10, 2019



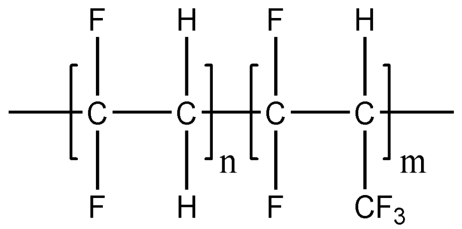
- Fluoropolymers are promising materials for PDRC applications

Coatings deposition

SOLUTION PREPARATION

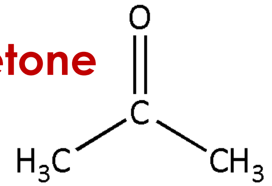
Polymer

Fluorinated (co)-polymers

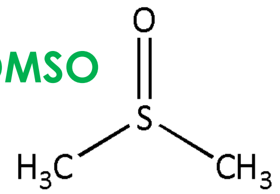


Solvents

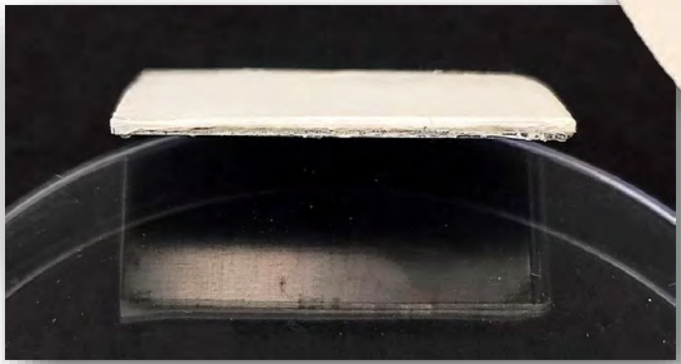
Acetone



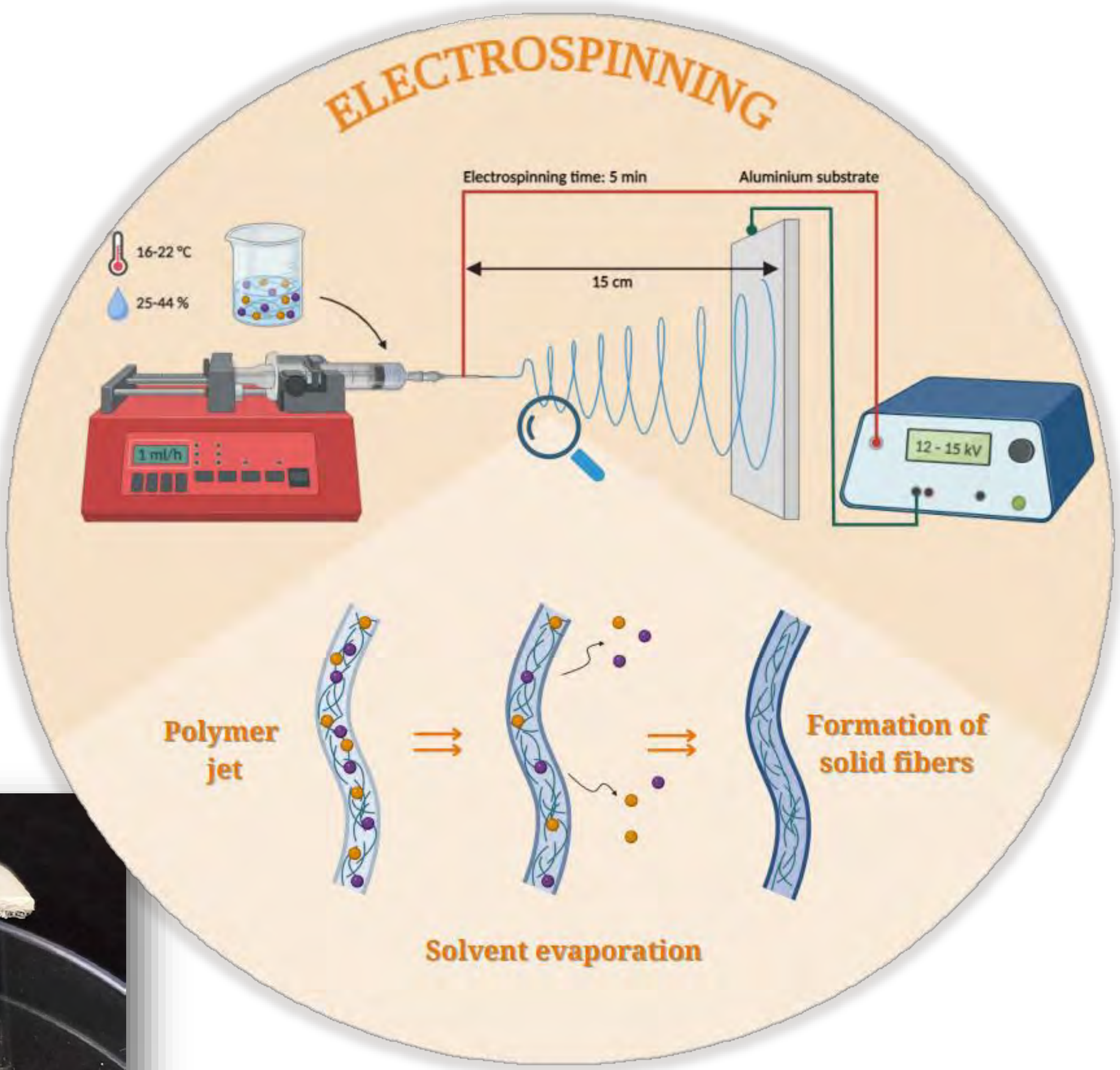
DMSO



Dimethyl sulfoxide

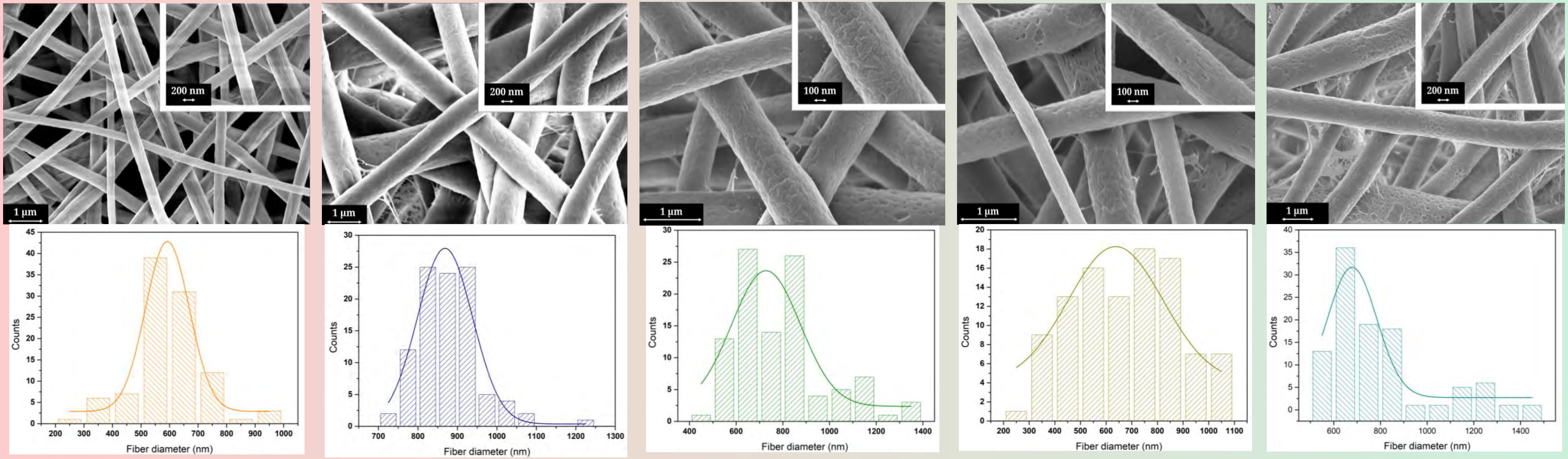


Nanofibrous coatings on metallic substrates



Control of nanostructured morphology

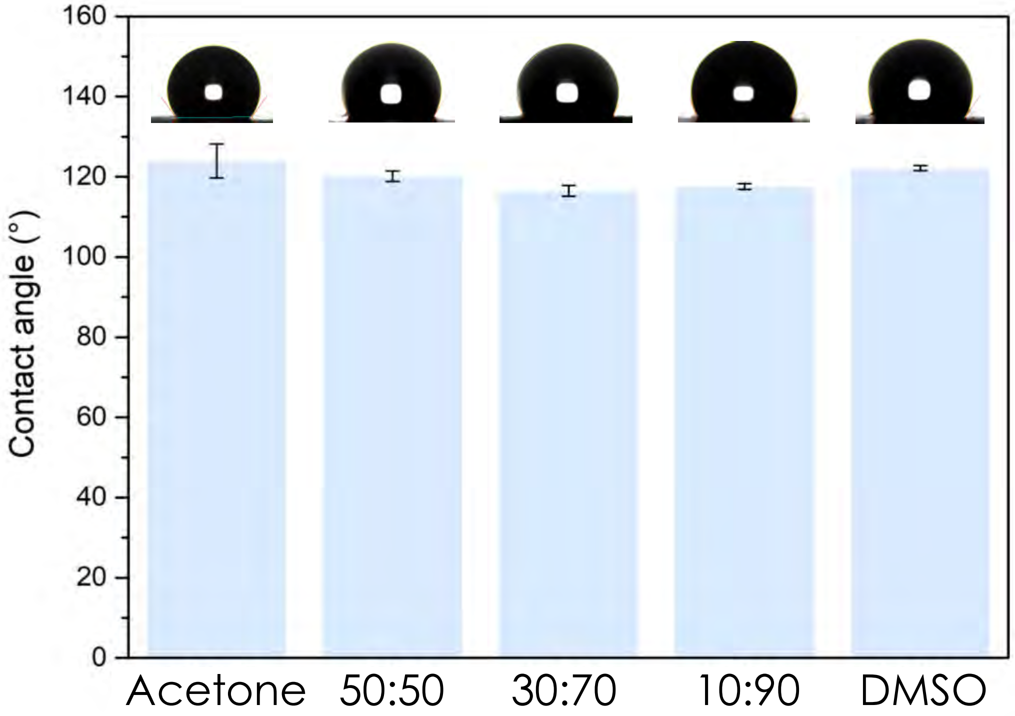
Acetone **DMSO**



- Mean fiber diameter
- Fiber diameter distribution and porosity
- Solar reflectivity

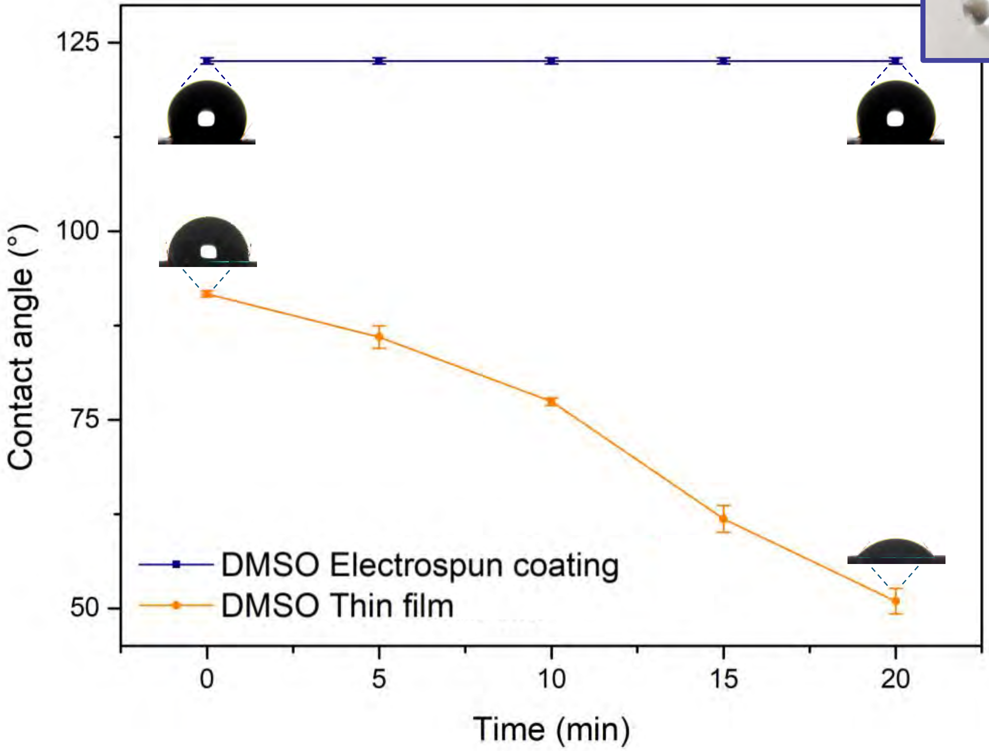
Surface properties

Water contact angle tests



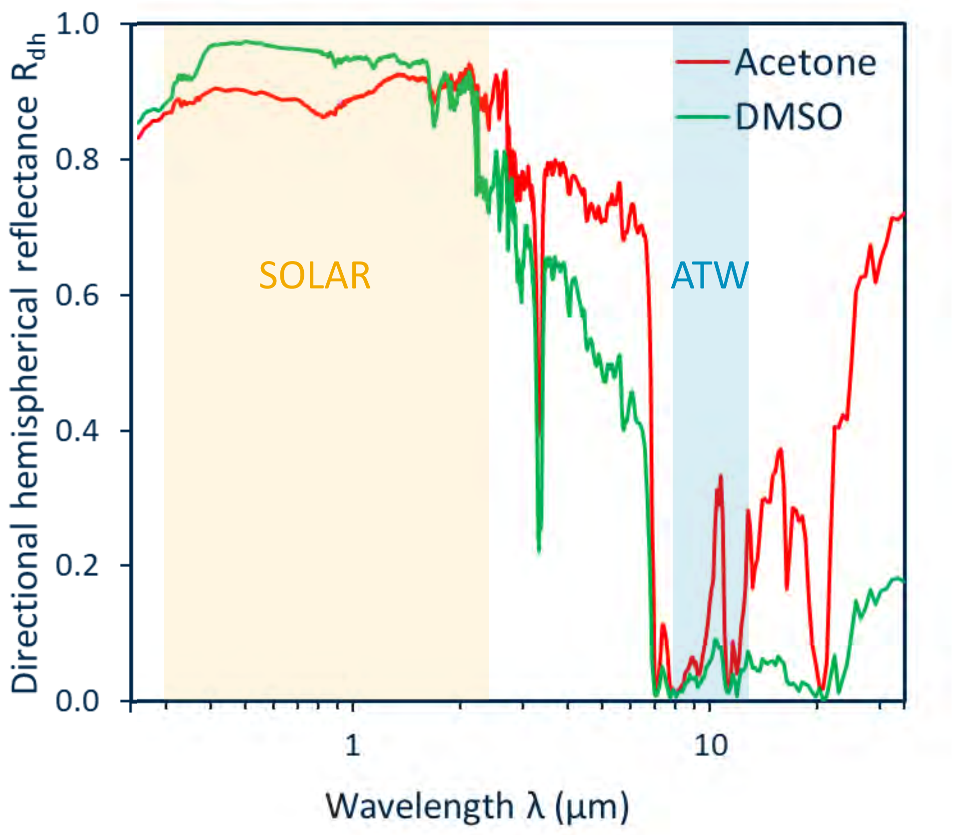
- Hydrophobic coating, independently on the solvent

- Stable wettability over time



Spectral properties

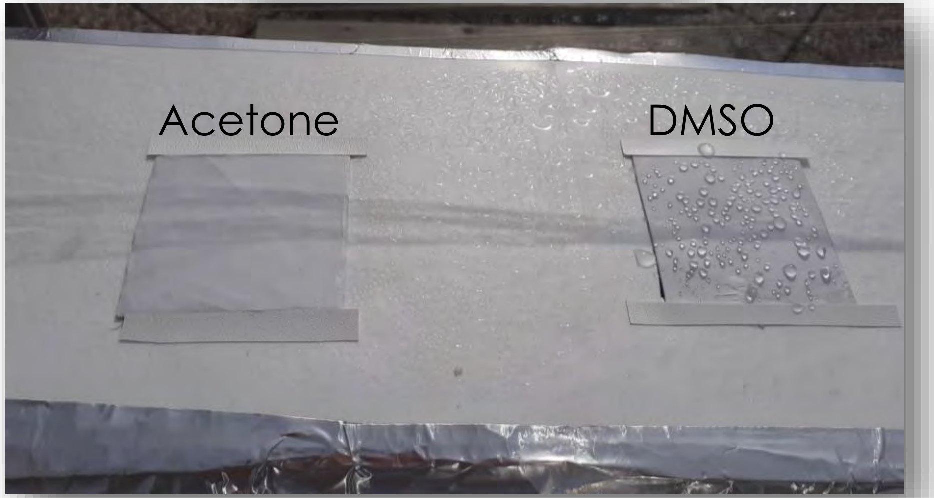
Infrared-optical characterization

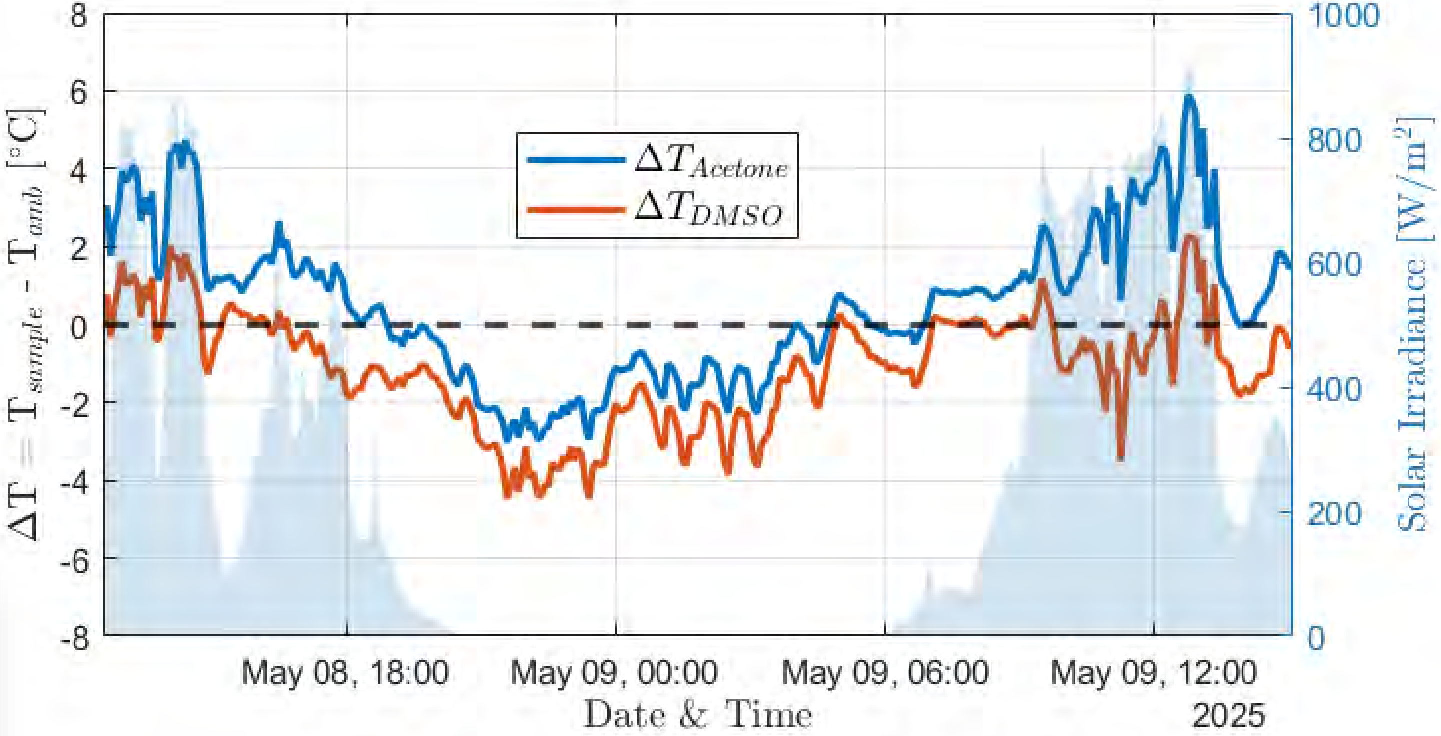


Sample	Acetone	DMSO
Normal thermal emittance ε_{IR} at @ 300 K	0.73	0.92
Solar absorptance a_{solar} @ 300 K	0.11	0.05
Thickness (µm)	75	107
Density (g/cm³)	0.87	0.65
Porosity (%)	50	65

- Promising spectral properties for PDRC applications
- Effect of the nanostructured morphology (density and porosity)

Outdoor cooling performance

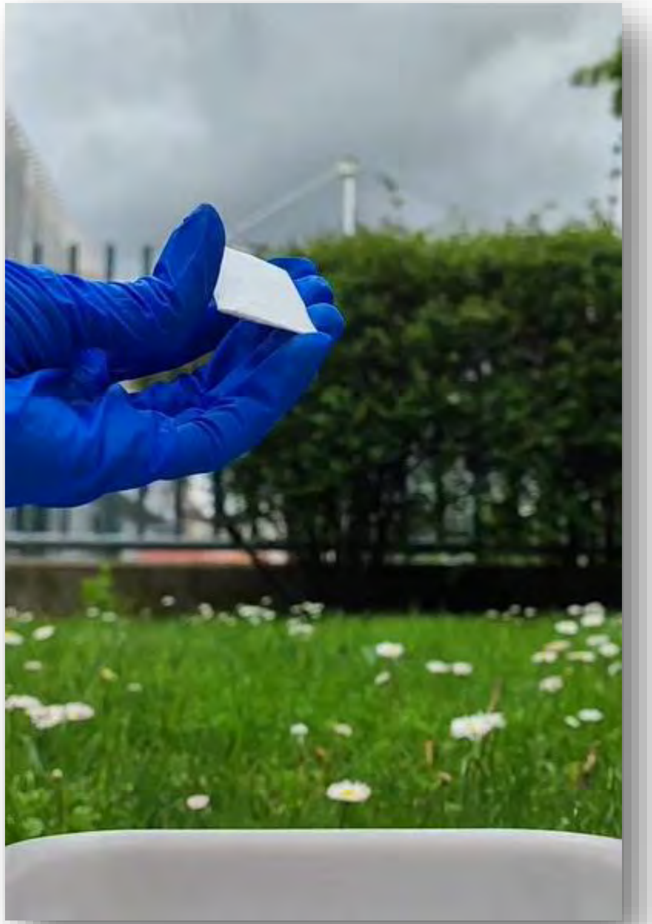




- Good cooling properties → Maximum sub-ambient drop: -4°C
- Effect of the nanostructure features (density, fiber diameter distribution and porosity)

Resistance to environmental aging

Abrasion test

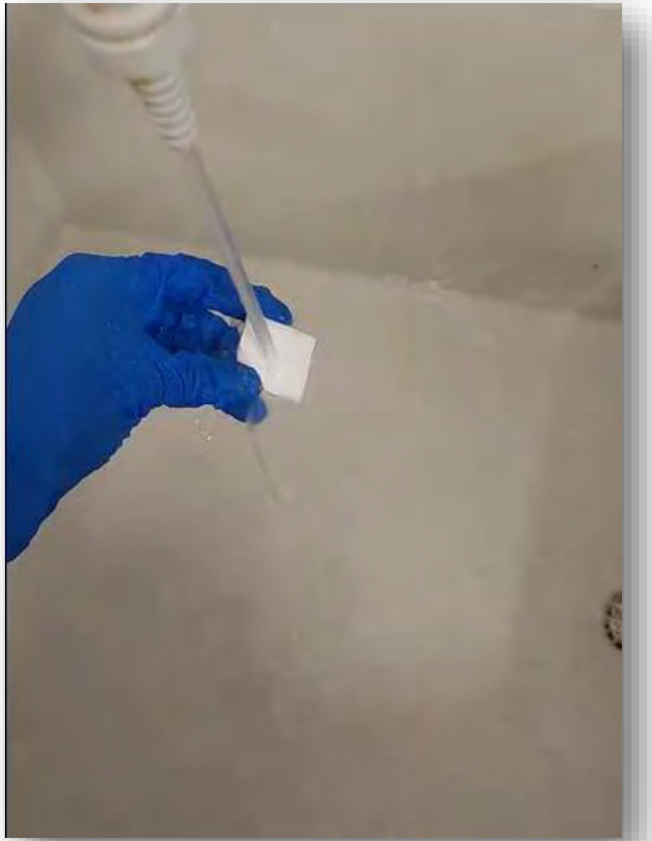


- Resistant to 50 cycles

Mud test

- Resistant to mud
- Self-cleaning behavior

Water-related weathering test

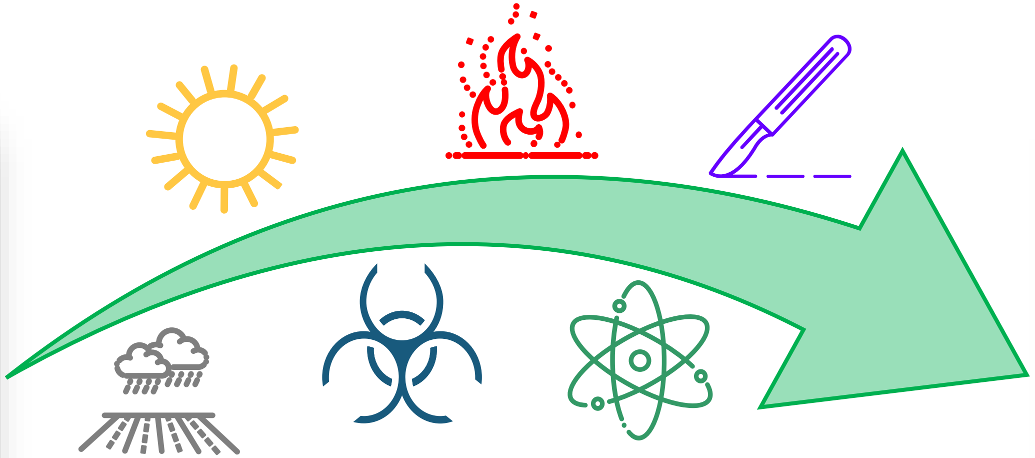


- Resistant to high-speed and high-pressure water jets

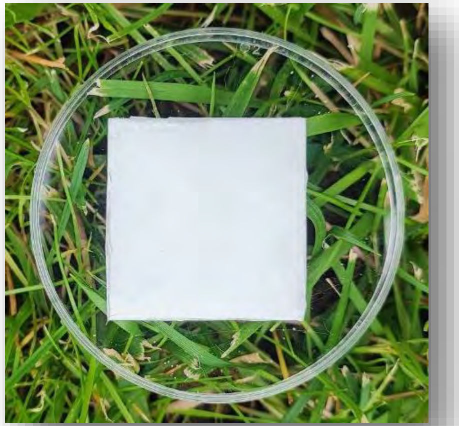
Resistance to environmental aging

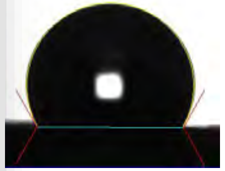
122 ± 0.7°

Before



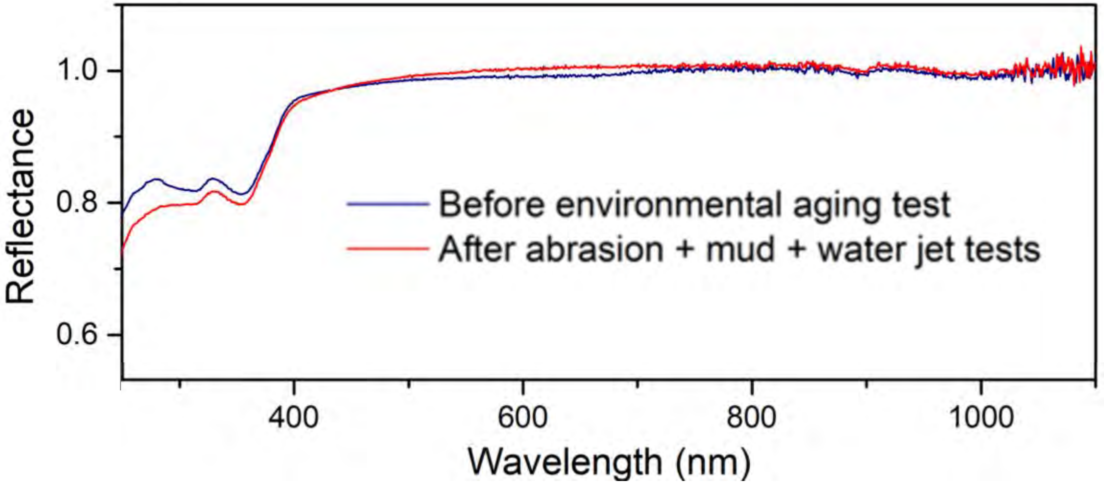
After





121 ± 1.2°

UV-Vis spectroscopy – Integrating sphere

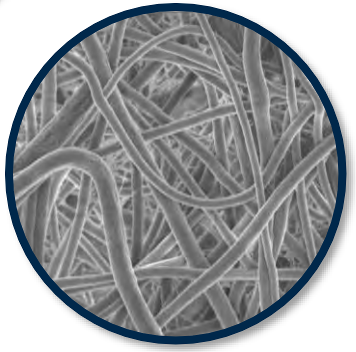


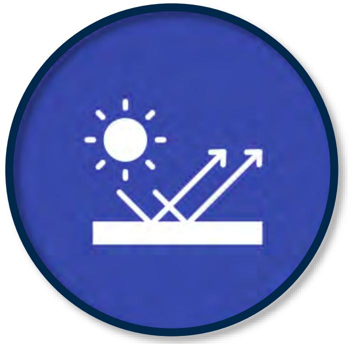
- High resistance to different soiling and weathering agents
- No significant spectral changes after the aging tests

J. A. Talamo Ruiz *et al.*, Manuscript in preparation

Conclusions and perspectives

- Electrospinning enables nanofibrous coatings for efficient PDRC
- Porosity, surface area, and spectral response are tunable
- Fluorinated coatings: hydrophobic, durable, aging-resistant, efficient
- Nanostructure + chemistry → maximized radiative performance
- Future: greener, sustainable polymers for eco-friendly PDRC





Electrospun nanostructured coatings offer a powerful route toward durable, high-performance, and sustainable PDRC solutions

Acknowledgements

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DI RICERCA METROLOGICA

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Polymeric Materials
MPMNT Group
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Thank you!

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