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Introduction

Temperature plays a key role in several industrial fields¹, biological processes and health care applications. While traditional, remote and contact-based, thermometry techniques have been instrumental in understanding macroscopic thermal phenomena, they face significant limitations at the nanoscale. At this level, heat transfer transitions from diffusive behaviour (Fourier's law), governed by continuum mechanics, to ballistic regimes, where energy carriers such as phonons or electrons propagate without scattering. This characteristic makes the use of contact sensors and black-body radiation-based techniques unreliable while also adding complexity to typical temperature uncertainty estimation approaches. Novel nano-thermometry techniques seek to bridge this gap, by facilitating the extraction of accurate local temperature information within a system at sub-micrometre spatial resolution. Such measurements are essential to understand micrometre scale and nanostructured systems in fields such as; quantum technologies (opto-electronics, photonics), biology (cell behaviour), medicine (targeted cancer therapies, early disease diagnosis, etc.) and advanced engineering (nanofluidics, efficient energy storage, advanced materials, etc.).

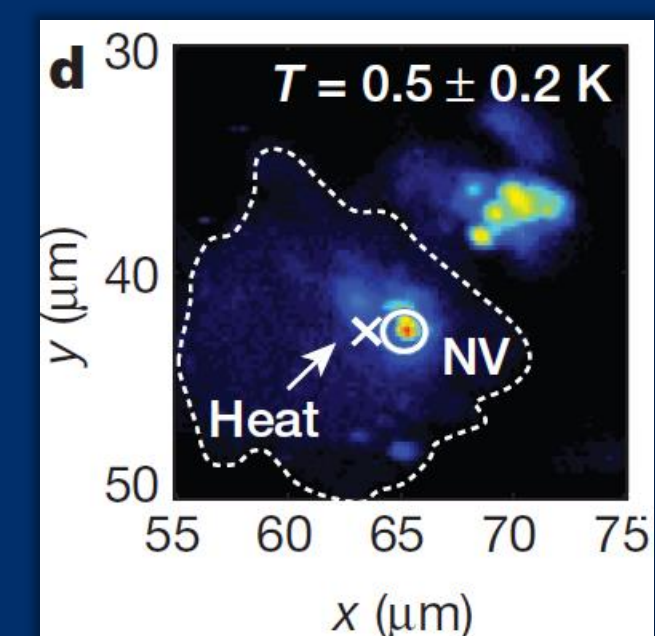
Luminescence Nano-thermometry

Luminescence nano-thermometry has emerged as a promising optical-based technique² able to address the aforementioned challenges. This approach leverages the temperature dependence of luminescent properties (spectrum shape, excited states lifetime, excitation rise time, etc.) of nanometre-sized particles embedded and in close thermal equilibrium with the medium of interest. This technique yields up to sub-micrometre spatial resolution with minimal perturbation and relatively short integration times. However, it currently lacks metrological standardisation which limits its confidence and reproducibility across several applications

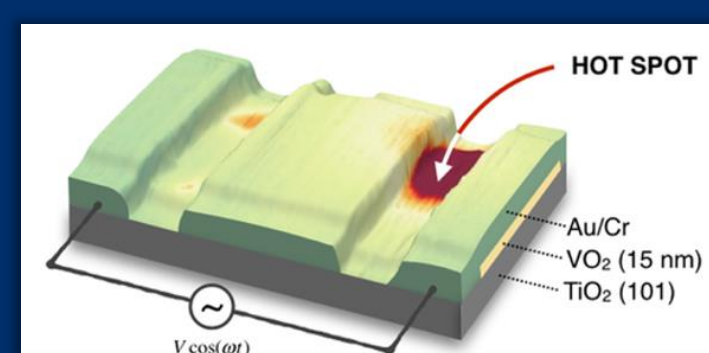
Main objectives of this work

1. Investigate the heat transfer characteristics at the nanoscale by expanding current NPL designed luminescence metrology numerical models to understand the implications of local temperature and interactions at the nanoscale
2. Explore the temperature-dependent luminescence behaviour of specialized luminescent nanoparticles, such as nanodiamonds (NDs) with luminescent nitrogen vacancy – NV – centres, and improve their performance to operate as reliable remote temperature sensors using imaging-based microscopy systems; and,
3. Define the essential requirements for establishing traceable temperatures for the luminescence nanophosphors while optimizing their performance.

Luminescence nanoscale thermometry applications



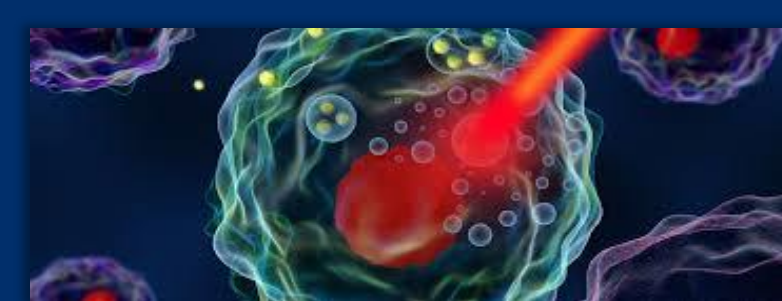
Biology
Thermal driven/triggering process for cell division³



Quantum technologies
Hot spots detection in nano electronics⁵

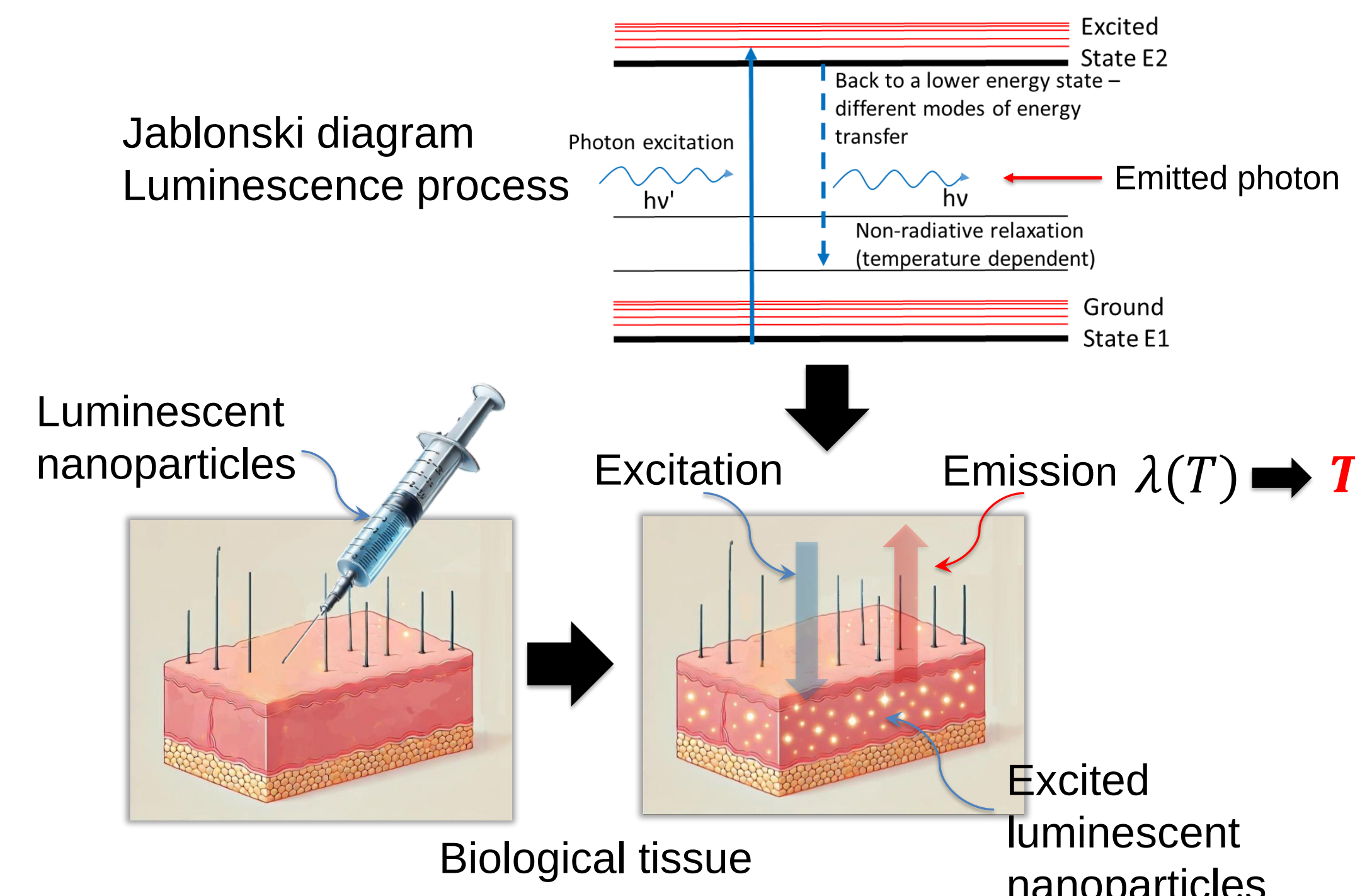


Fundamental thermodynamics
Thermometry in rarefied gases⁴

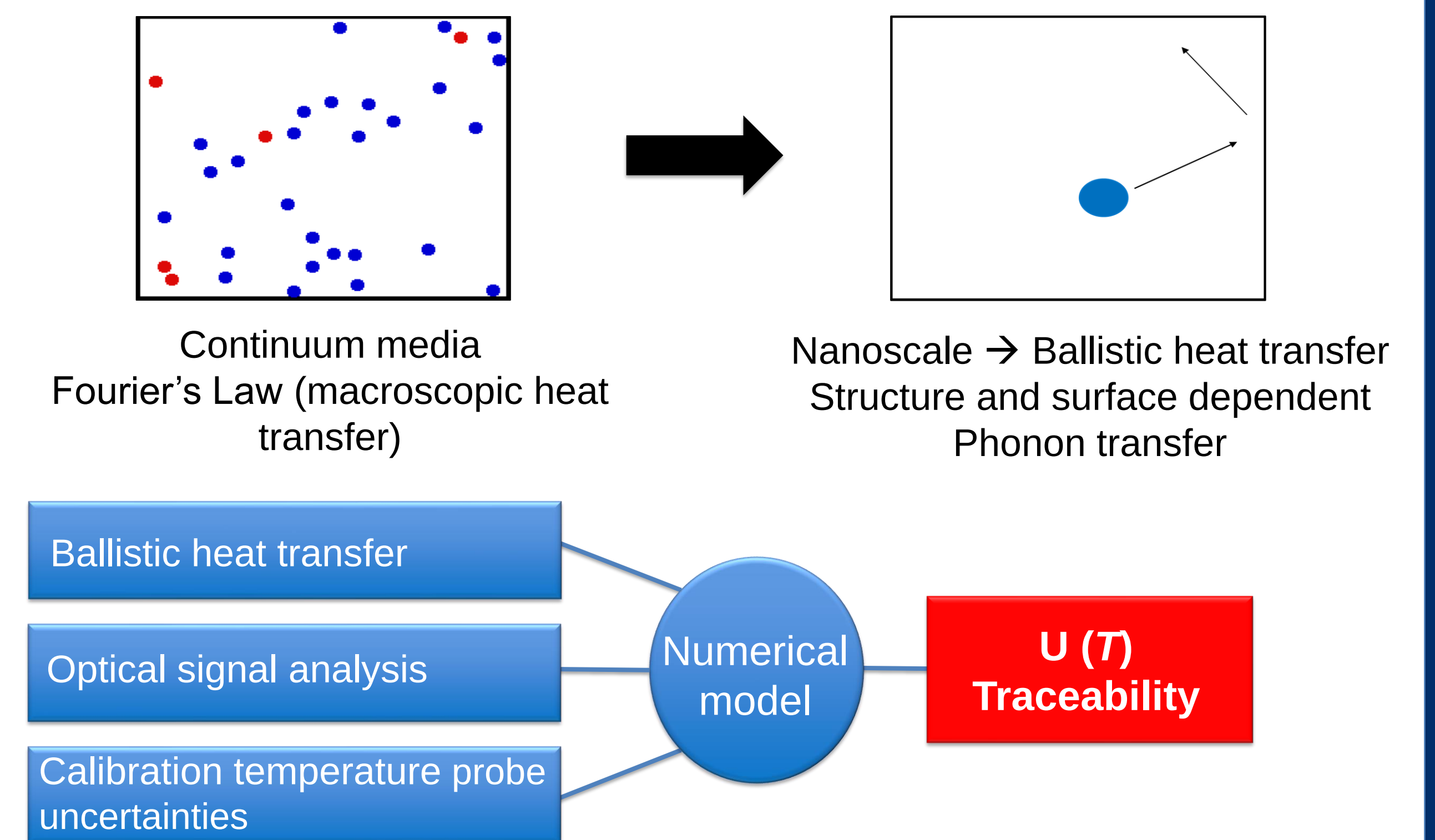


Healthcare
Cancer research
Photothermal cancer treatment monitoring⁶

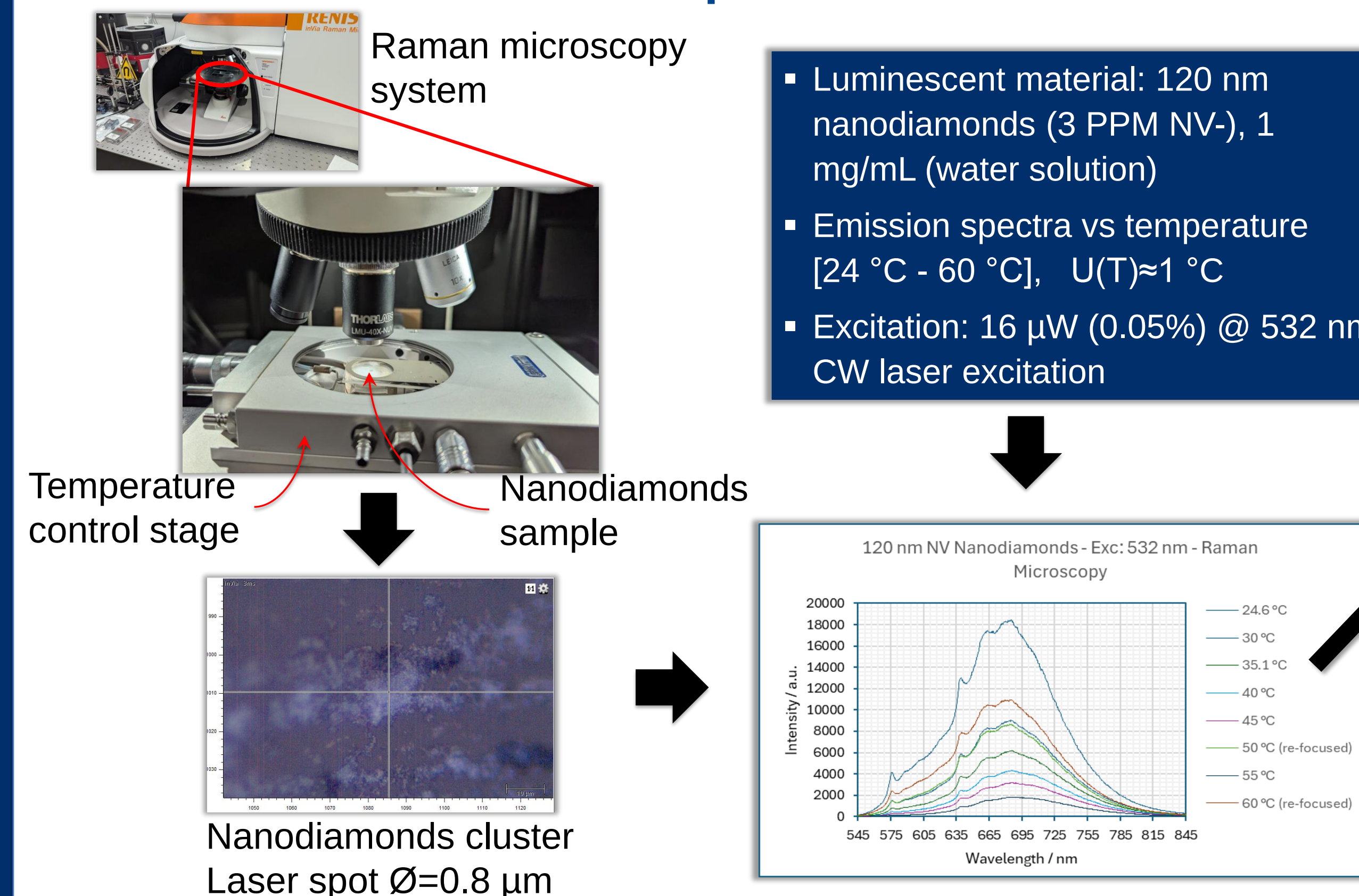
1. Luminescence nano-thermometry for biology concept



2. Temperature uncertainty modelling

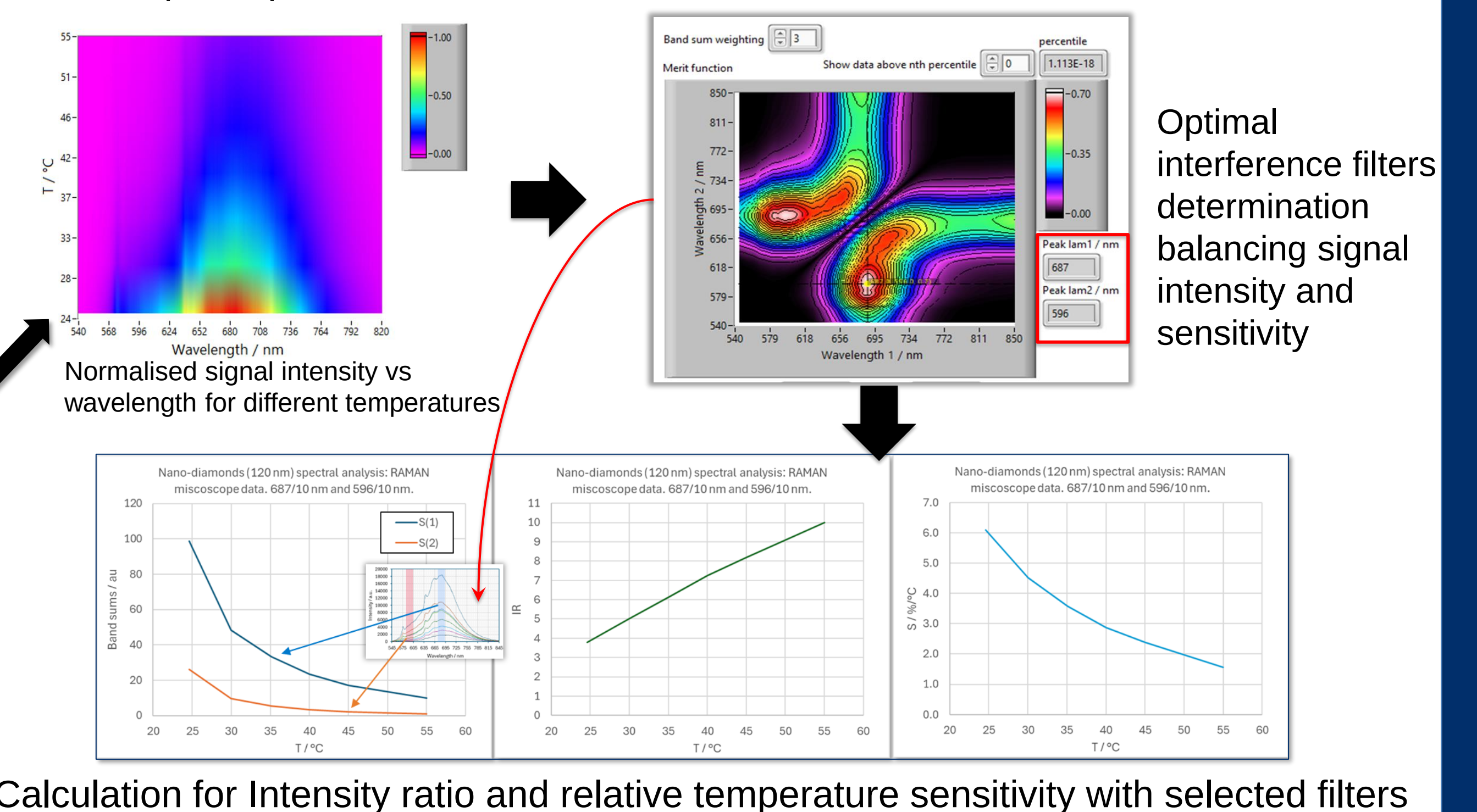


3. Measurement setup for initial assessment



4. Temperature sensitivity optimisation

Intensity ratio approach: filters band optimisation for 120 nm NDs using, NPL developed, spectral assessment software



Summary

Building a metrology framework will help luminescence nanoscale thermometry accelerate its integration into critical fields. This work addresses this issue by providing researchers with *in-situ* standardisation and traceability tools such as calibration and temperature sensitivity optimization. Understanding of the main uncertainties linked to ballistic heat transfer and optical signal analysis are key developments necessary for this journey.

Although first trial measurements using nitrogen vacancy nanodiamonds have shown excellent performance, our target is to expand the analysis to other luminescent nanoparticles and obtain a traceable temperature uncertainty below 1 °C with 0.1 °C resolution to make the technique attractive for practical use in healthcare and quantum technology applications.

Acknowledgments

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