



Science and  
Technology  
Facilities Council



# STFC Central Laser Facility

Capabilities relevant to Air Quality

Andy Ward

SAQN Launch Meeting, York, 14<sup>th</sup> January 2020

# CLF Facilities and Functions

GEMINI



High power,  
ultra-short pulse  
dual beams of  
15 J, 30 fs pulses

Pulse every 20s

VULCAN



Ultra high-power  
laser

Up to 1 PW peak  
power

Focused intensity  
>  $10^{21}$  Wcm<sup>-2</sup>

**High-power, ultra-intense  
lasers for extreme conditions  
science & applications**

ARTEMIS



fs and as  
ultrafast  
spectroscopy  
IR to soft x-ray

ULTRA



Ultrafast  
vibrational  
spectroscopy

OCTOPUS



Imaging, laser  
tweezers and  
microscopy

**Research Complex**  
at Harwell

**Laser applications in the physical and life  
sciences (materials, chemistry, biology)**

# Application to Air Quality

GEMINI



VULCAN



ULTRA



OCTOPUS



CLEAN AIR TECHNOLOGY

AEROSOL STUDIES

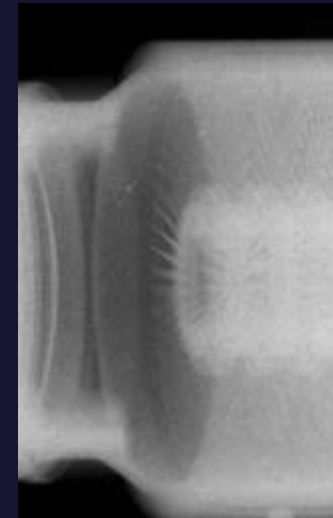
?

SAQN STFC  
AIR QUALITY  
NETWORK

# Flash Radiography

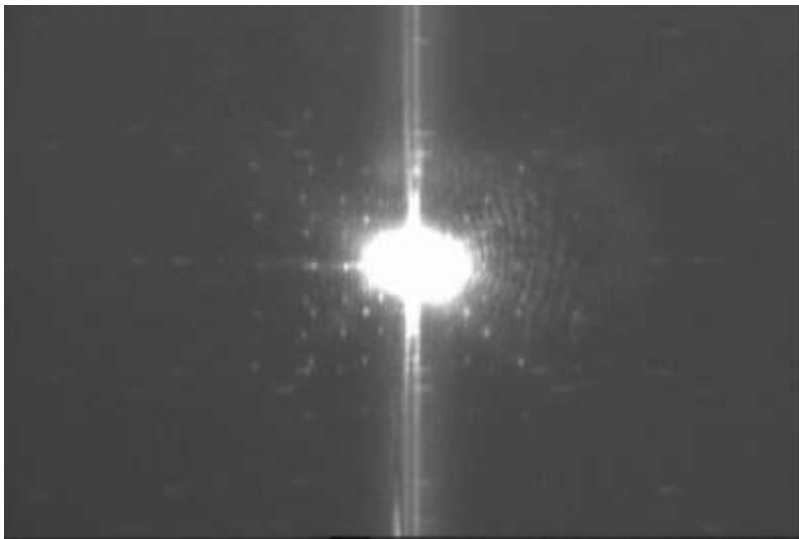
## X-ray imaging of engine components

- Imaging through high density materials
- X-rays generated from short (fs) high intensity laser pulses on foil targets
- Aluminium blades @ 42,000 rpm
- With 100 micron resolution



# Laser trapping of aerosol

- Side on views of trapping
- Water droplets from a nebulised mist



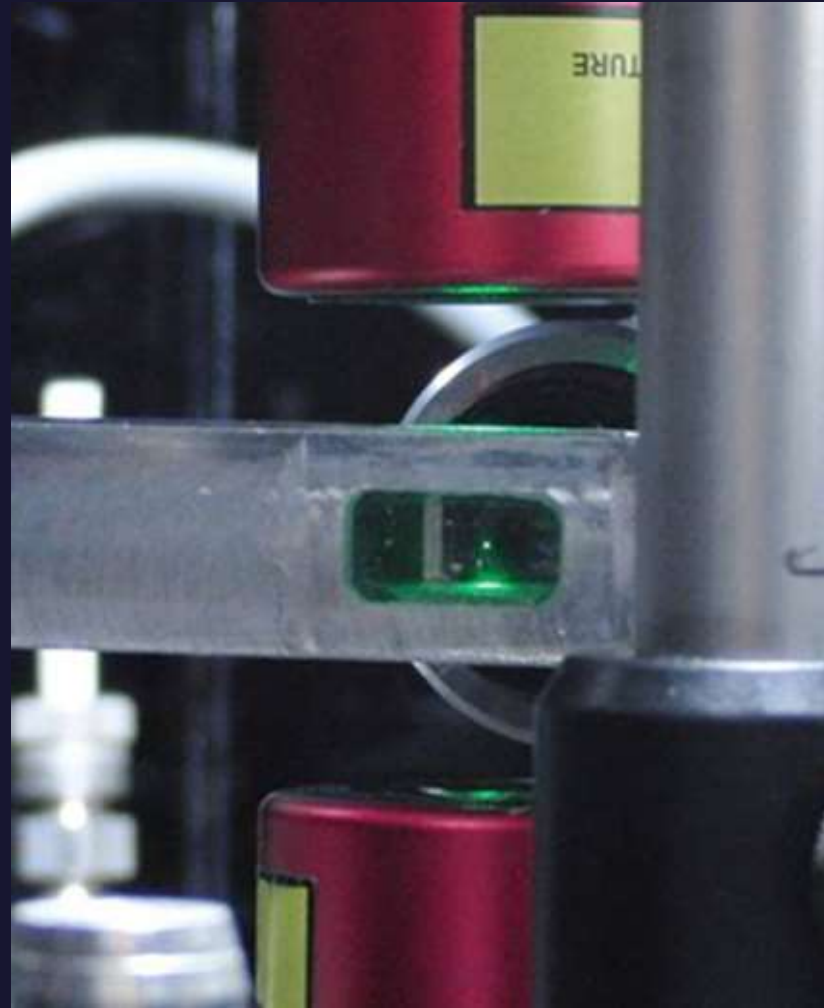
Nd:YAG Laser scatter



Laser optically filtered 50  $\mu\text{m}$

# Aerosol trapping

- Typically single droplet studies
- Droplets can be held for many hours.
- Multiple particles can be manipulated to study collision behaviour
- Analyse aerosol with a range of imaging and spectroscopy techniques



# Aerosol composition

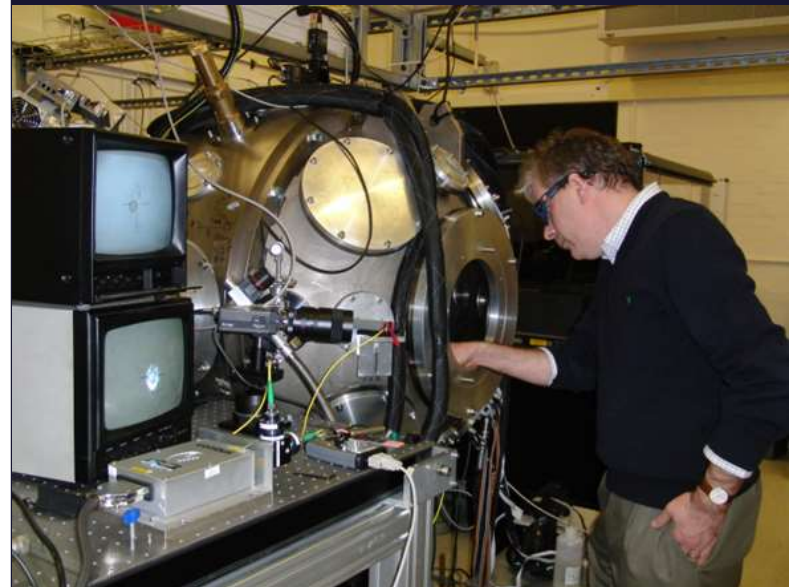
- Liquid: aqueous droplets, organic and hydrocarbon droplets, monomers.
- Solid: polymers, silica, titania, alumina, pharmaceutical aerosol.
- Solid cores with liquid shells
- Size range: 0.1 to 15 microns (typically 1 micron)

Cloud chemistry,  
mineral dust, pollution,  
organics



# Experimental conditions

- Aerosol delivery: nebulisation, atomisation, pMDI
- Laser wavelength: 514.5, 532, 785, 1064 nm
- Laser powers: between 1 and 25 mW
- Controlled environments: humidity, temperature, pressure, surrounding gasses, etc



# Chemical, physical and optical properties of aerosol particles

Chemical  
characterisation  
- Raman Micro-  
spectroscopy

Uptake of trace  
species

Heterogeneous  
surface chemistry

$O_3$

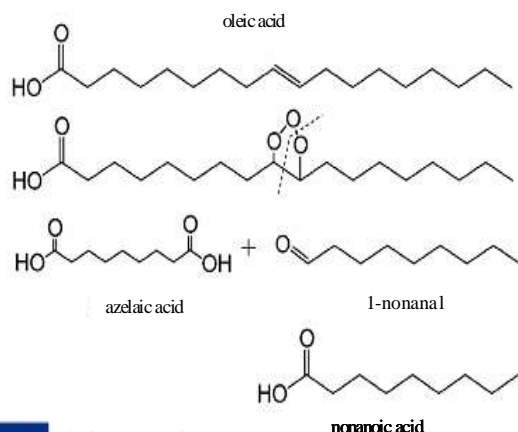
Reactive uptake

Physical  
Transformations  
- FLIM  
- Mie Scattering  
- SAXS

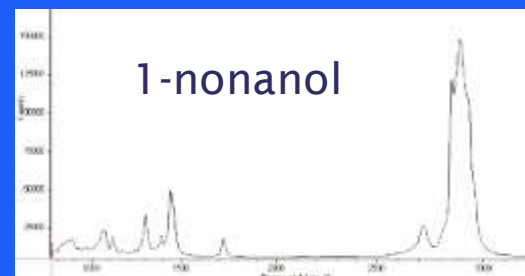
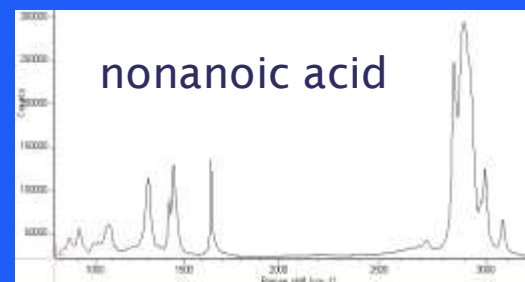
Mass transfer

# Micro-Raman Spectroscopy

- Levitate an airborne droplet consisting of oleic acid and water
- Droplet is exposed to a dilute flow of humidified ozone in oxygen
- Acquire and analyse spectra

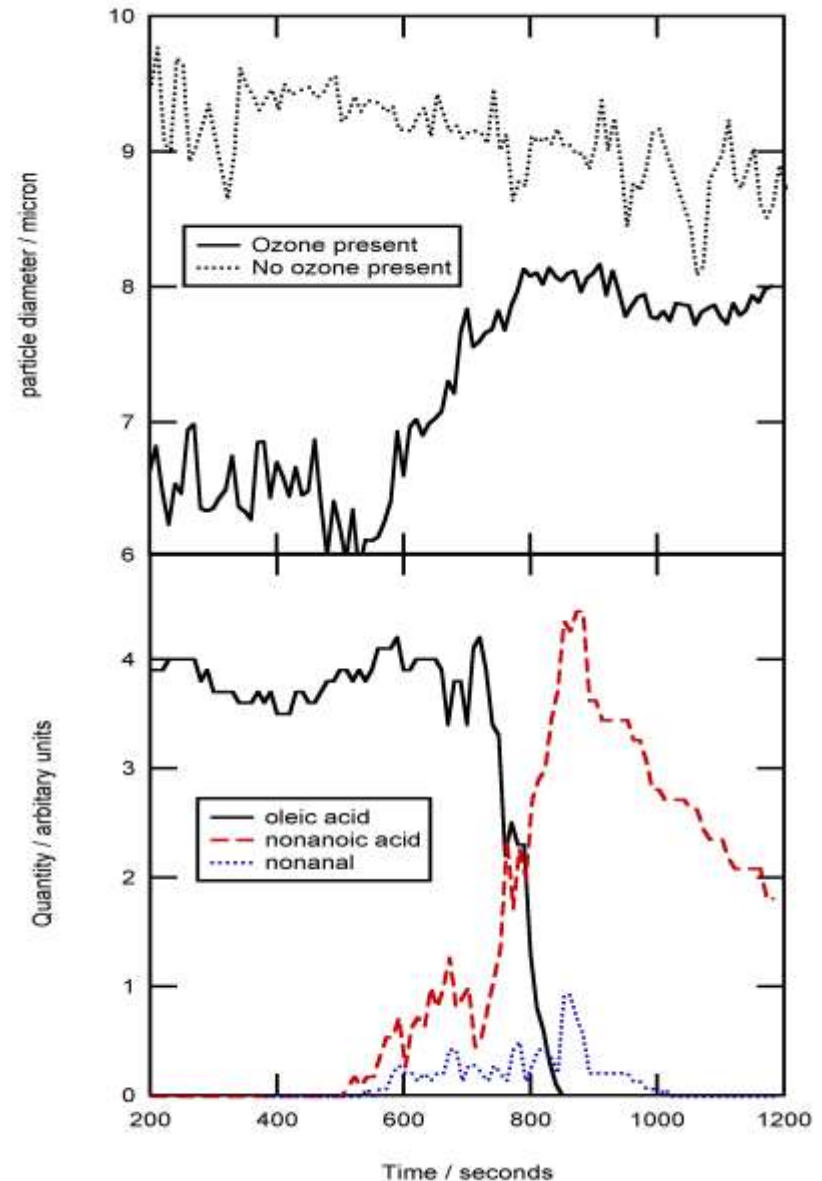


Reactants and products followed during the oxidation of oleic acid by ozone.



# Micro-Raman Spectroscopy

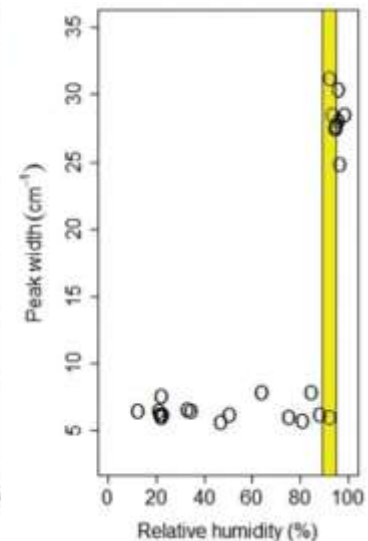
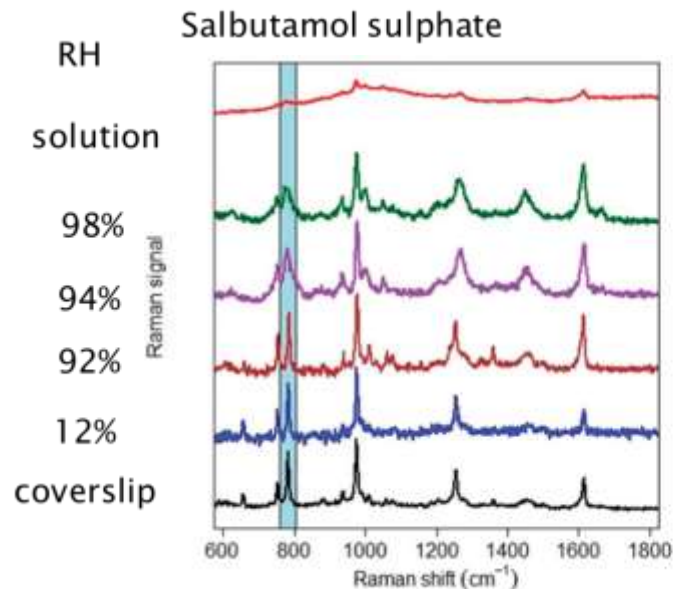
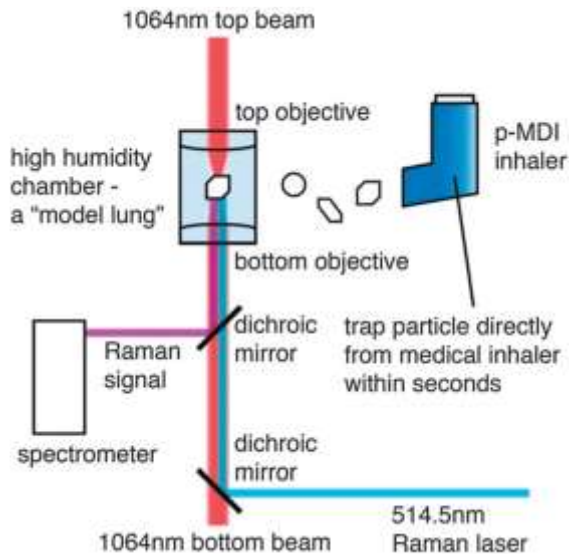
- Growth of the droplet size was observed as the droplet became more hydrophilic
- The oleic acid on the droplet was oxidised and the decay of reactants and the growth of chemical products was followed with Raman spectroscopy.



# Respiratory Therapy Studies

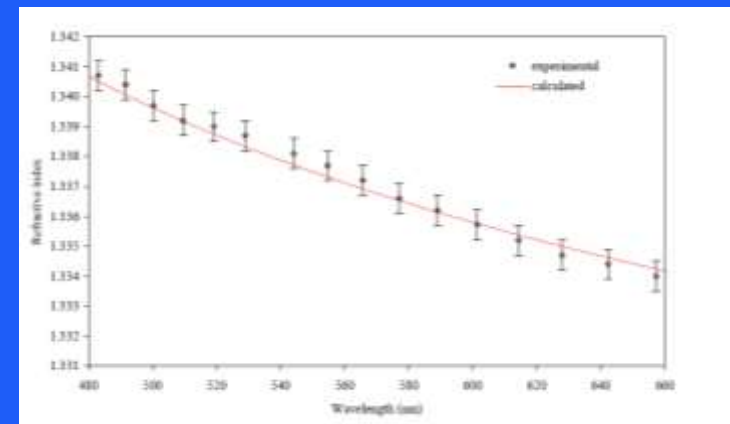
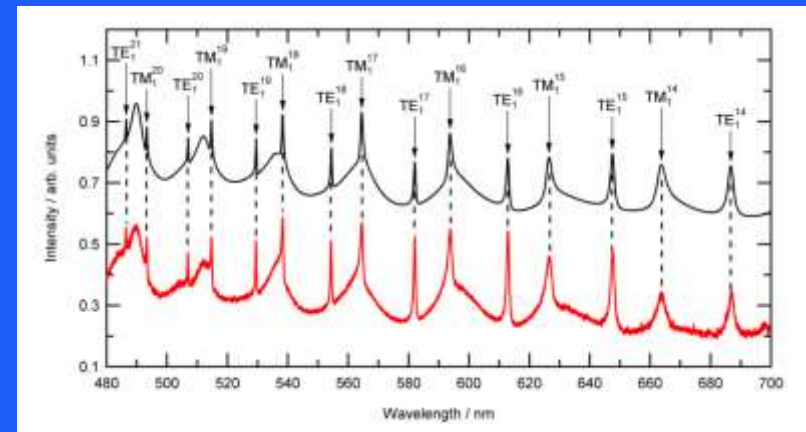
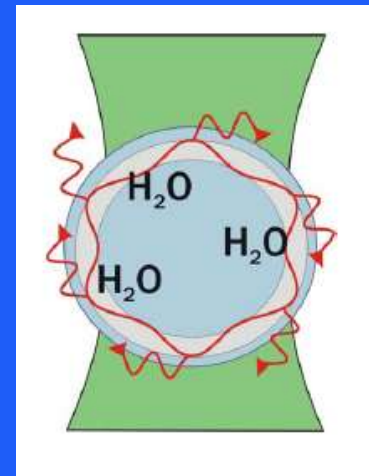
Francis Pope, Birmingham

Optical levitation of particles in air from a medical inhaler. Allowing chemical changes to be monitored whilst simulating the respiratory environment of a lung



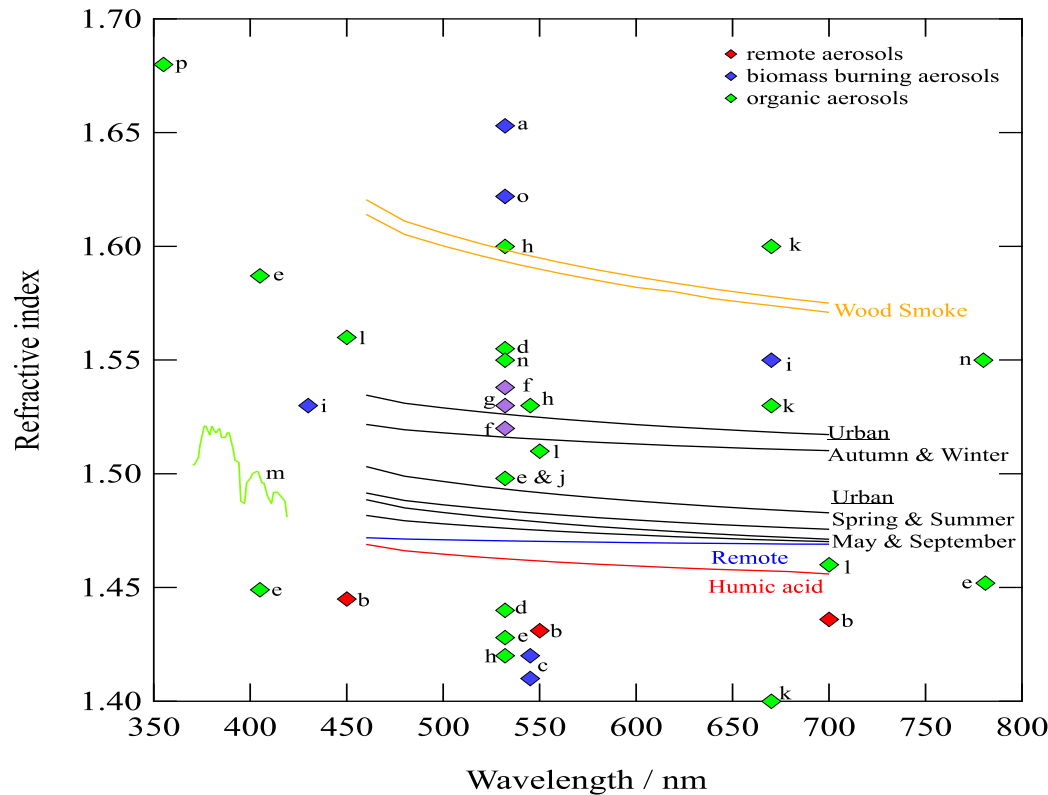
# Mie Scattering Spectroscopy

- The droplets act as cavities or whispering gallery modes (WGMs)
- At specific wavelengths light can circulate for timescales of nanoseconds, giving rise to metres of pathlength in a droplet that may be only a few microns in diameter.
- Use spontaneous Raman or broadband white light
- Optical properties: **Droplet size, refractive index**



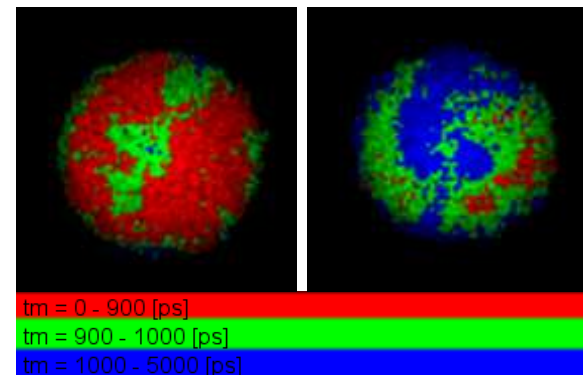
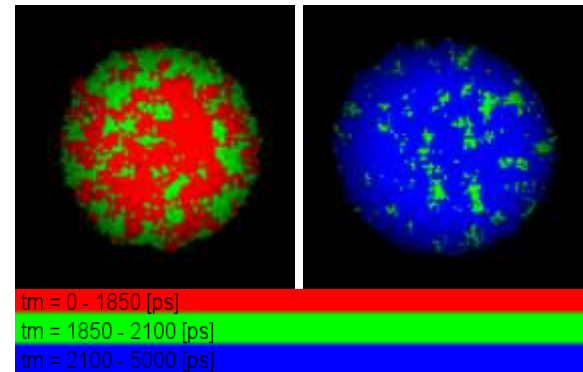
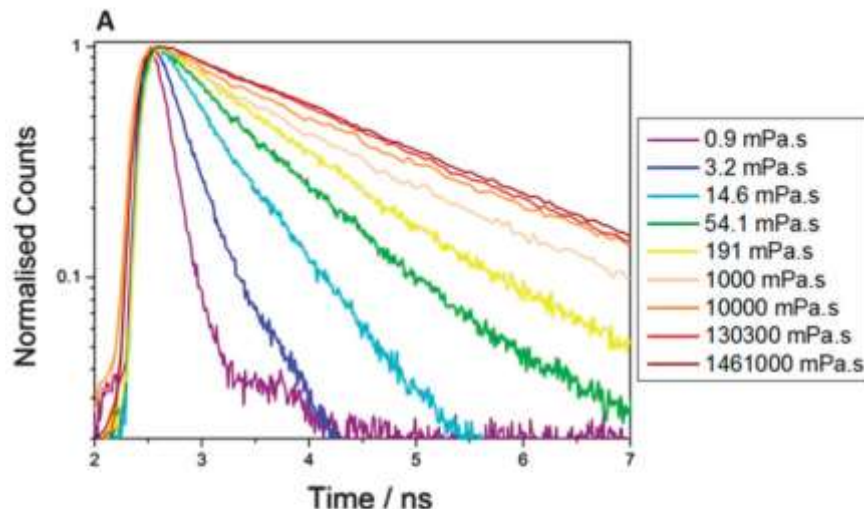
# Sampling atmospheric aerosol

- Re-aerosolise samples collected on filters from different environments



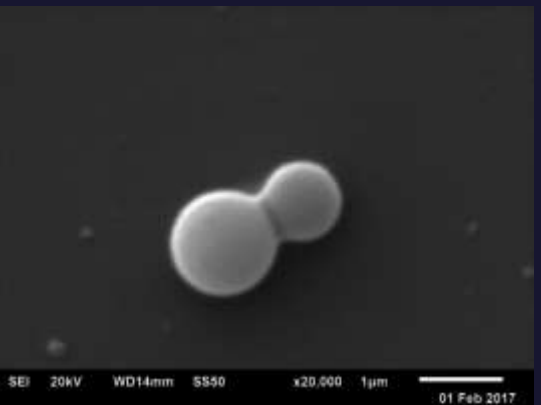
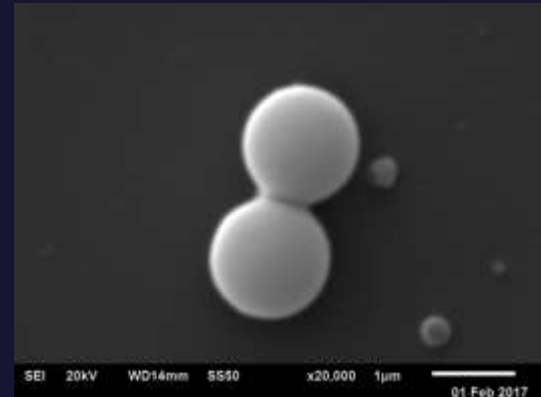
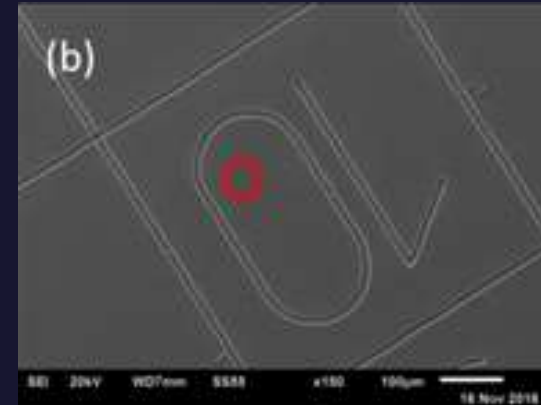
# Direct measurement of aerosol viscosity and phase using Fluorescent Lifetime Imaging (FLIM)

Viscosity measurements can be achieved using fluorescence detection from small fluorophores (“**molecular rotors**”).



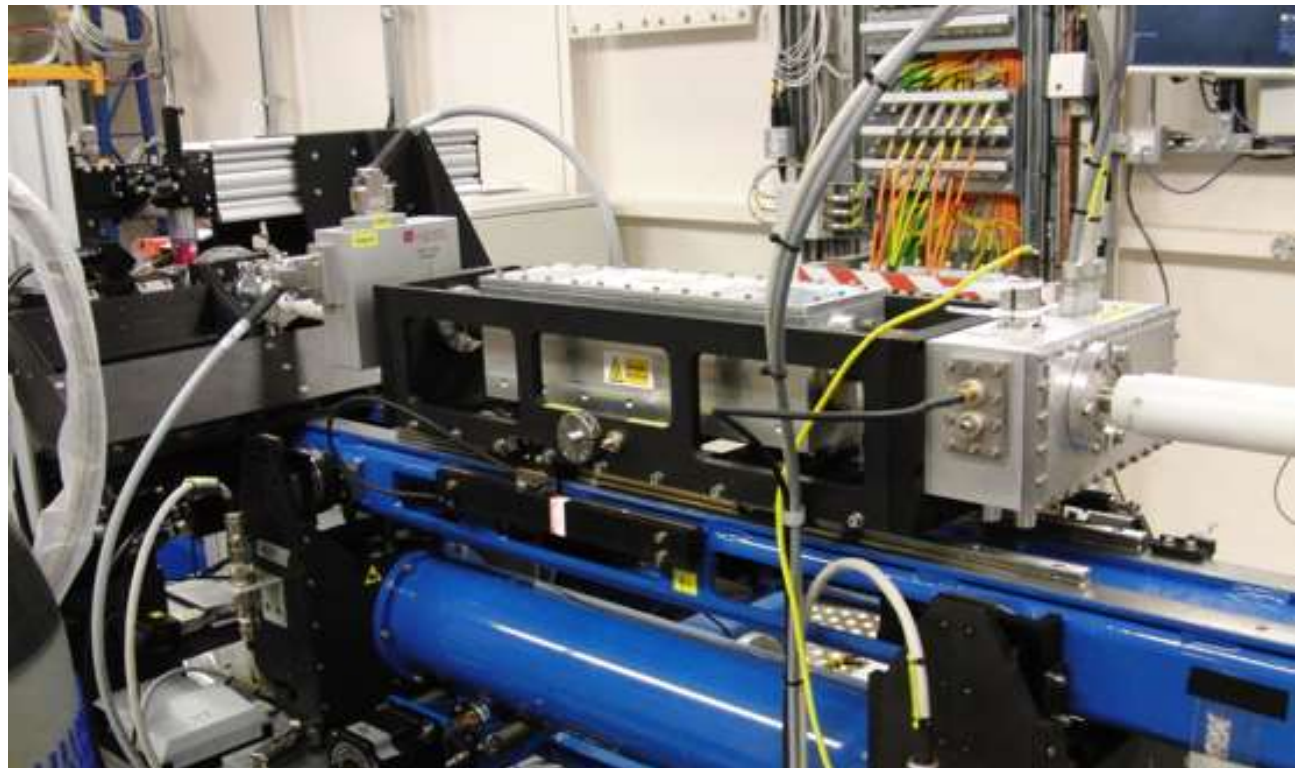
# Correlative studies with electron microscopy

- Capture two droplets in air – monomer
- Initiate reaction
- Manipulate laser positions to collide
- Lower particle to substrate – known coordinate
- Image on electron microscope



# Small Angle X-ray scattering of aerosol

- Diamond Light Source (Beamline I22)
- Follow the self-assembly processes of surface active materials

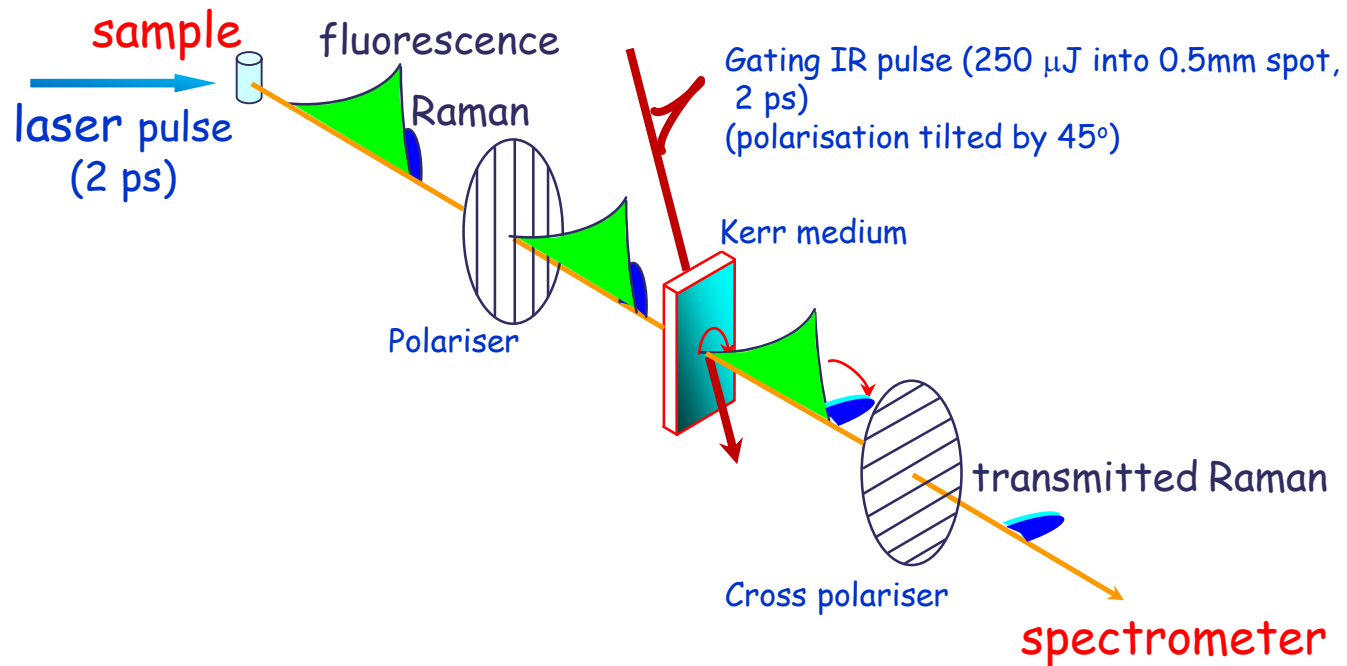


## SUPPLIMENTARY SLIDES



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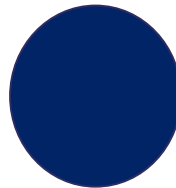
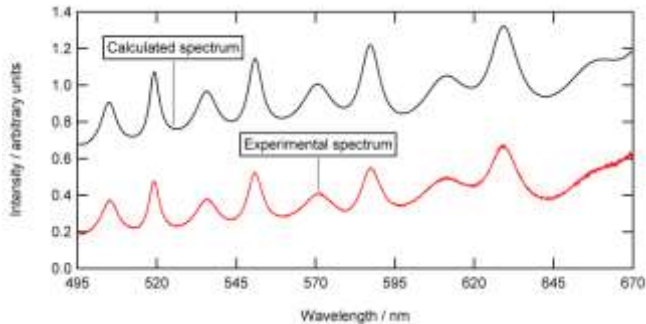
# Kerr gated Raman technique



*Kerr gated Raman is driven by **ps** laser  
Performance is sensitive to the gate spot quality*

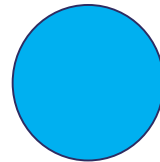
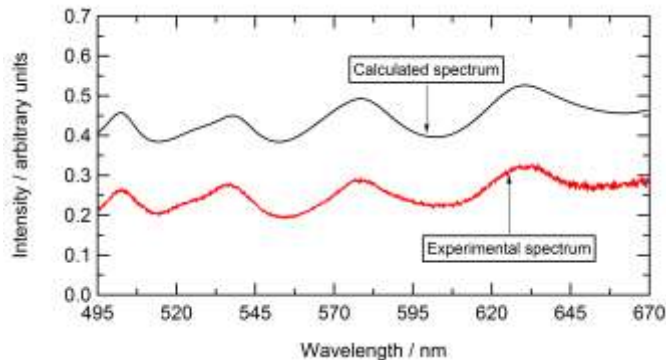
# Core-Shell Particles

- Coating with a vapour, using silica beads and oleic acid



- Oleic acid: size (1.055  $\mu\text{m}$ ) and refractive index dispersion

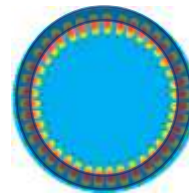
$$n = 1.4554 + \frac{4565}{\lambda^2} + \frac{1 \times 10^8}{\lambda^4}$$



- Silica: core size (0.956  $\mu\text{m}$ ) and refractive index dispersion

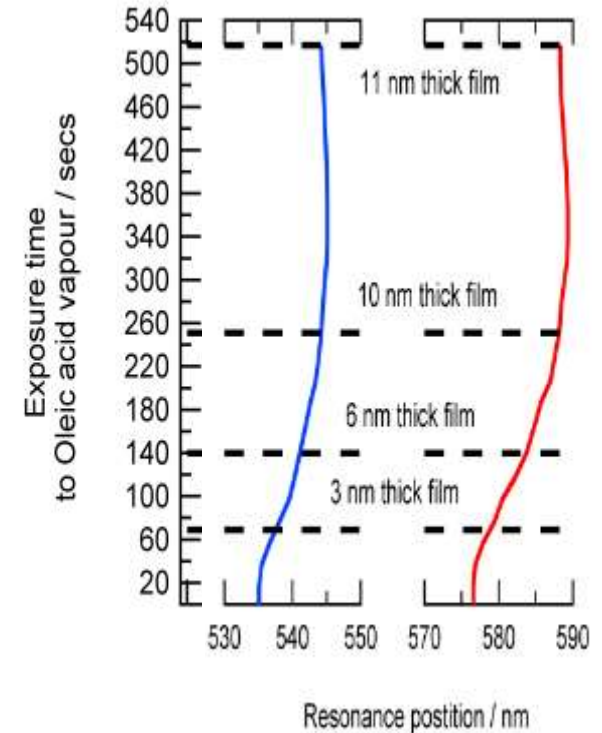
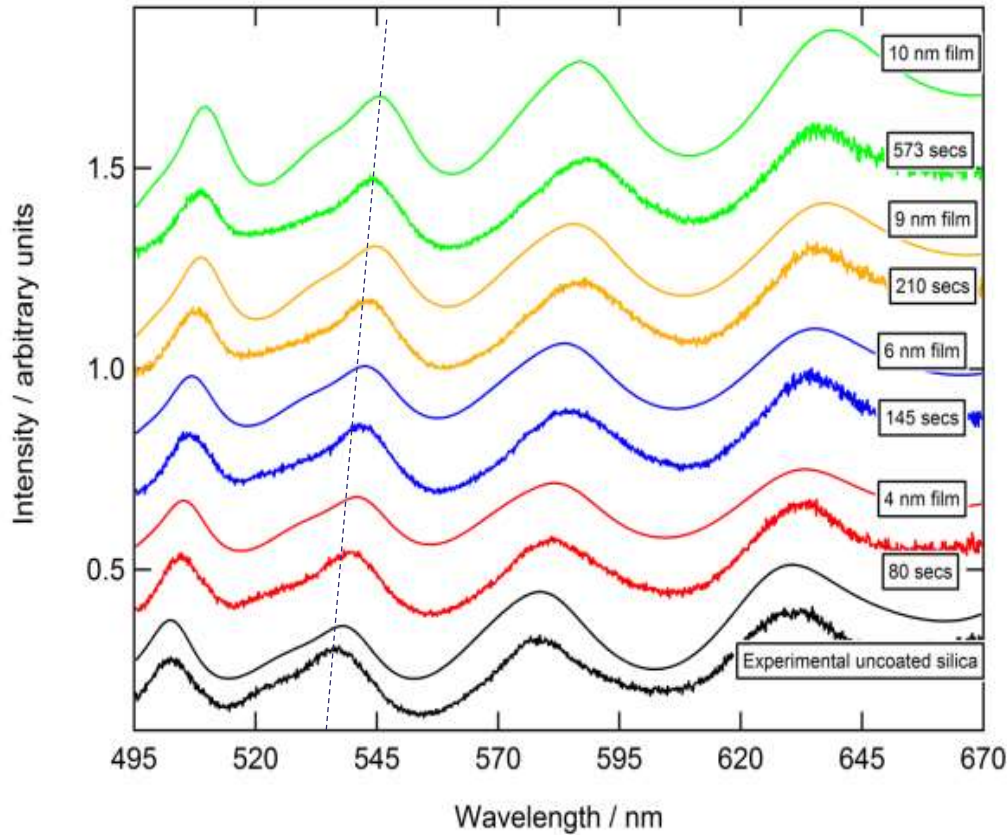
$$n = 1.3548 + \frac{3720}{\lambda^2} + \frac{1 \times 10^8}{\lambda^4}$$

- Coated sphere calculations use Aden-Kerker theory



# Core-Shell Particles

- Coating with a vapour, using silica beads and oleic acid



# FLIM viscosity calibration using aqueous sucrose droplets

