中国科学技术大学
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Experimental measurements and model studies on scattering properties of smoke particles

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Outline

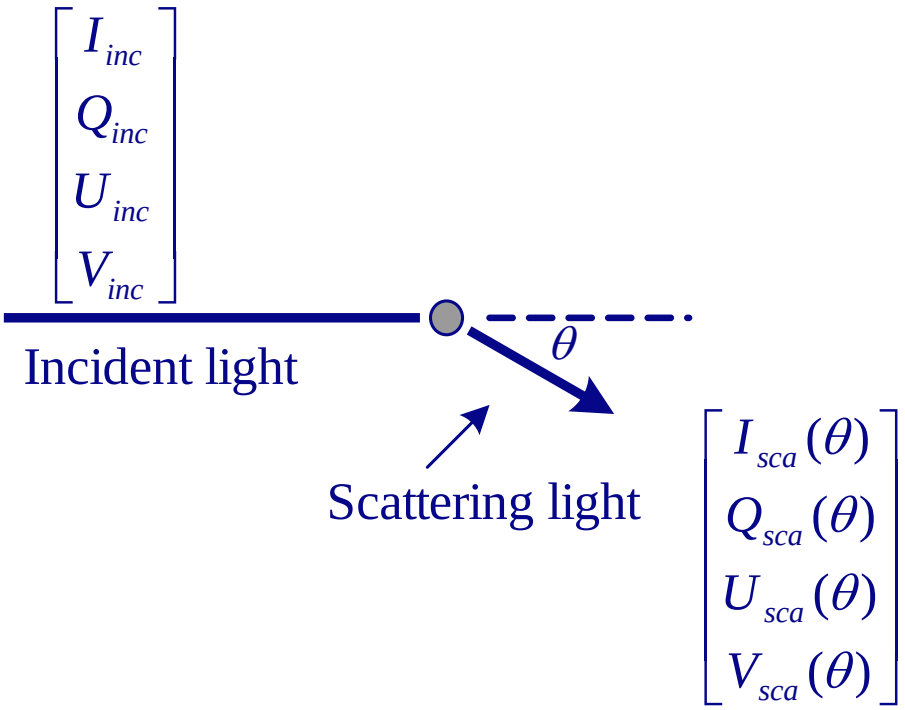
- Motivation
- Experimental measurement
- model study
- summary

Motivation

- Important for atmospheric remote sensing, climate change studies and fire detection etc.
- The optical properties of smoke particles may be diverse in different combustion conditions.
- Mie theory are often used in climate model. But it may be not applicable in many cases. So we verified the applicability of Mie and studied the optical properties of non-spherical particles.
- With the atmospheric aging, soot particles tend to be coated with non-absorbing materials, which leads to more complex morphology of soot particles

Experimental measurement

- Scattering and Stokes Parameters



- **Light beam can be represented by four Stokes parameters**

$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$ total intensity

$\pm$ 90° polarization

$\pm$ 45° polarization

circular polarization

Experimental measurement

- Mueller matrix

The transformation from incident light to scattering light can be represented by Mueller matrix:

$$\mathbf{I}_{sca}(\theta) = F(\theta) \cdot \mathbf{I}_{inc}$$

Scattering matrix Measurement and Modeling

$$F(\theta) = \begin{bmatrix} F_{11}(\theta) & F_{12}(\theta) & 0 & 0 \\ F_{12}(\theta) & F_{22}(\theta) & 0 & 0 \\ 0 & 0 & F_{33}(\theta) & F_{34}(\theta) \\ 0 & 0 & -F_{34}(\theta) & F_{44}(\theta) \end{bmatrix}$$

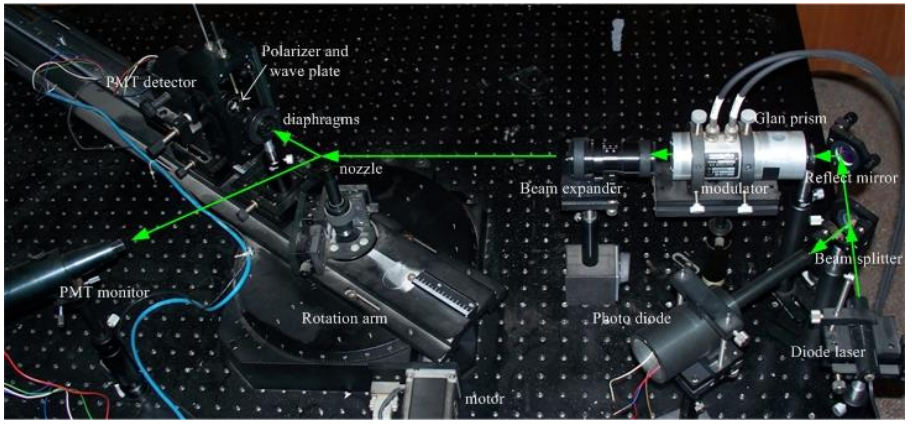
$F_{11}(\theta)$ (well-known as phase function) reflects the intensity from incident light to scattering

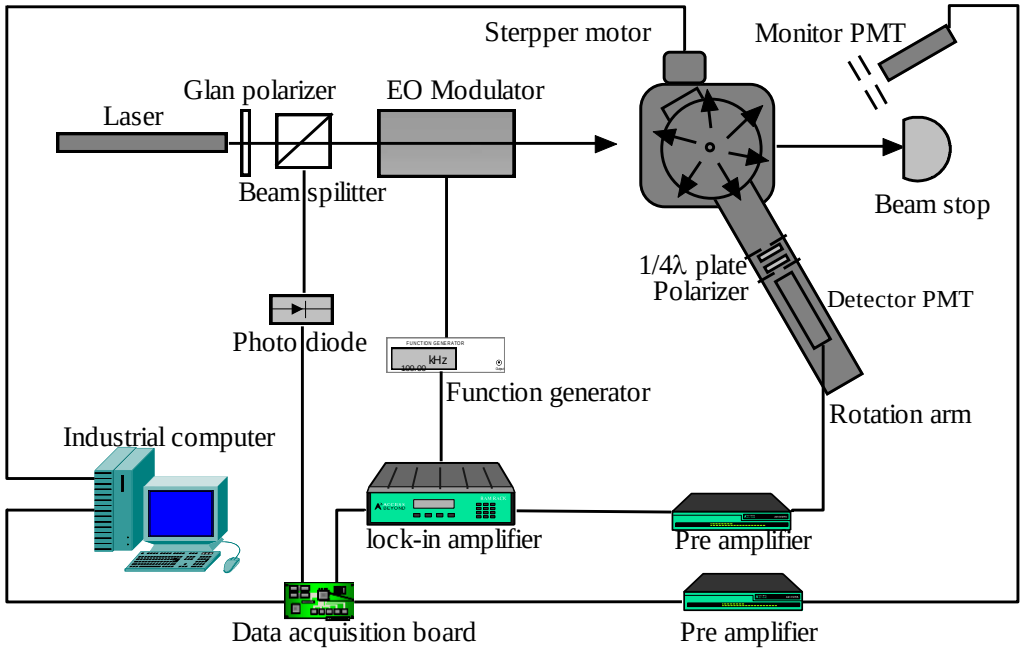
$F_{22}(\theta)$can be used to evaluate the total nonsphericity

Experimental measurement

- Experimental setup

Laser source: diode laser with wavelength of 532 nm





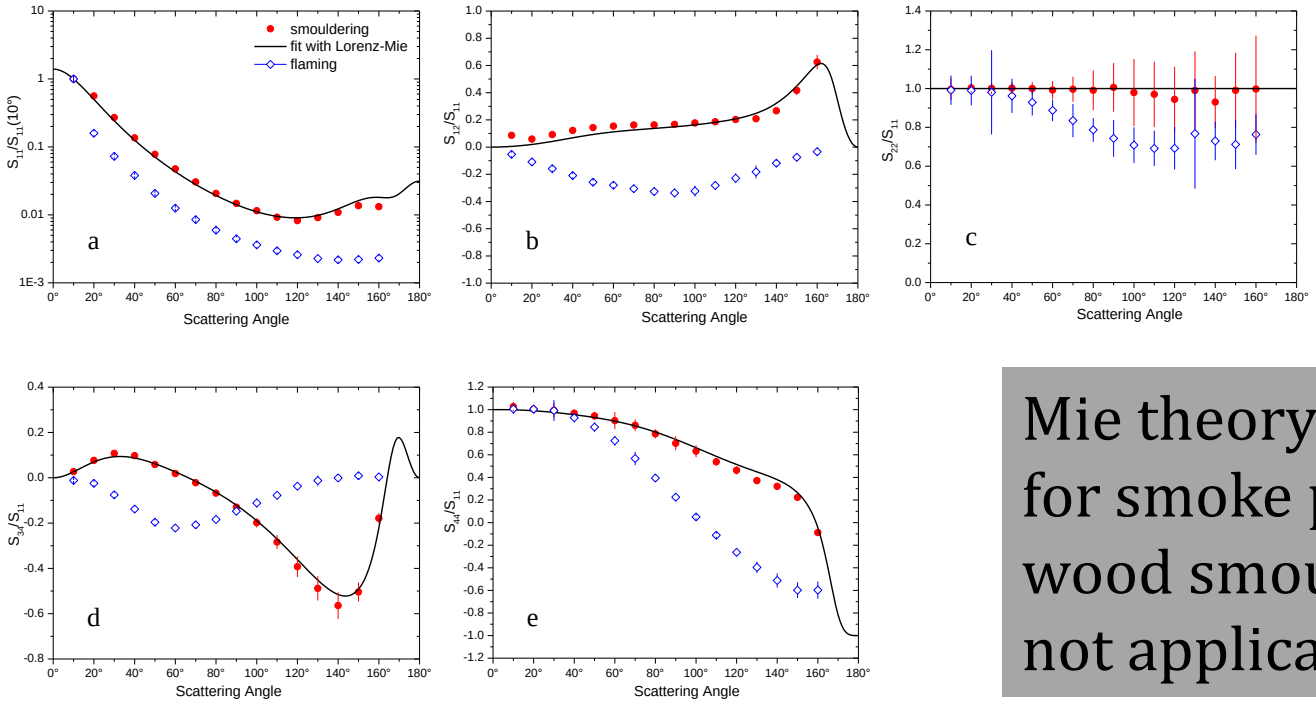
Measurement: 16 elements of Mueller scattering matrix

Scattering angle range: 5° ~ 160°

Angular resolution: 0.0045°

Experimental measurement

- Compared with Mie theory

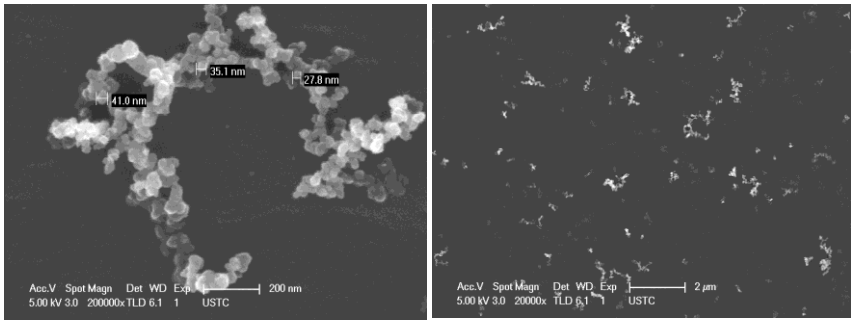


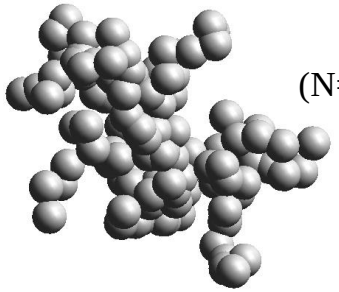
Mie theory is applicable for smoke particles of wood smouldering, but not applicable for flaming

smoke particles of smouldering and flaming wood fire at 532 nm

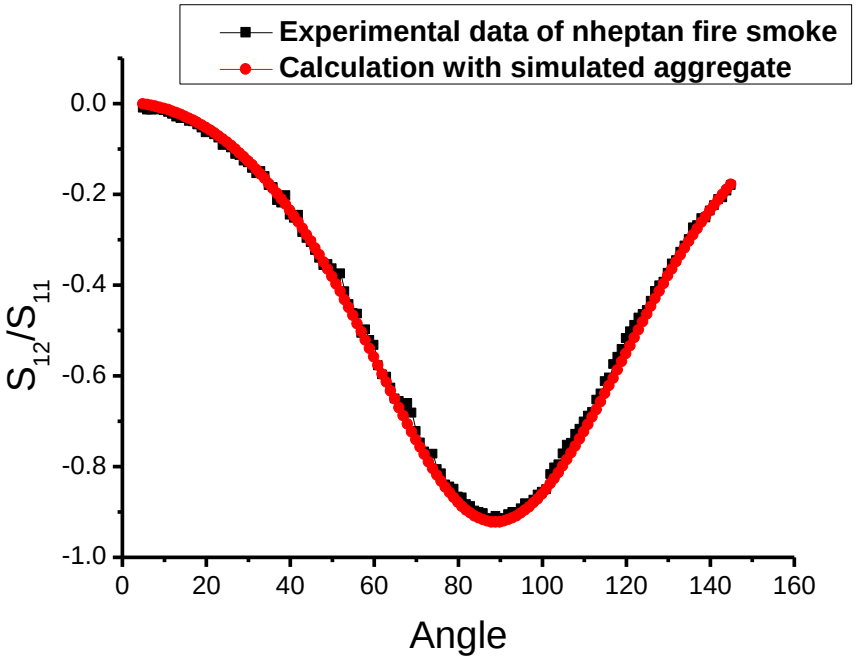
Experimental measurement

- Compared with fractal model



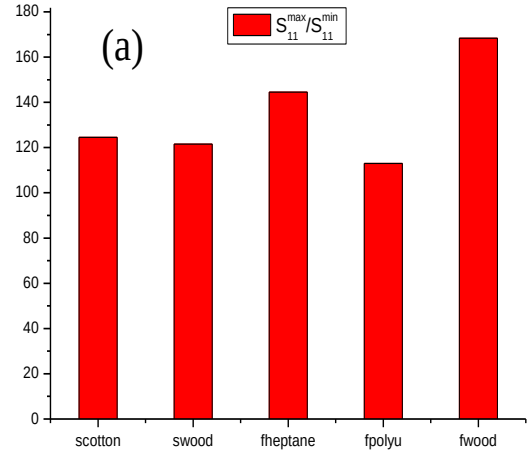


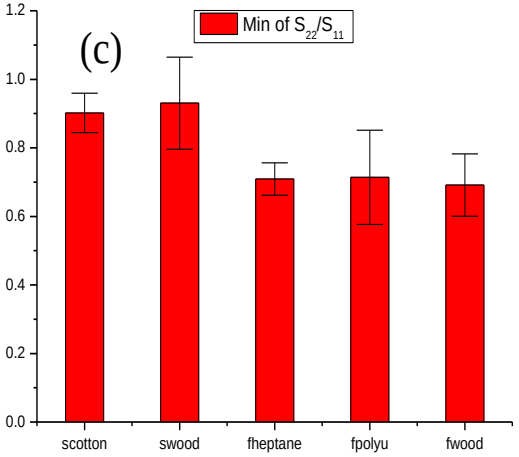
Simulated aggregate
(N=117, D_f=1.85, k_f=3.77)

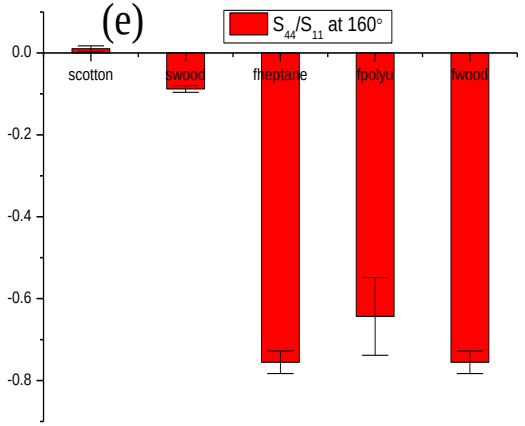


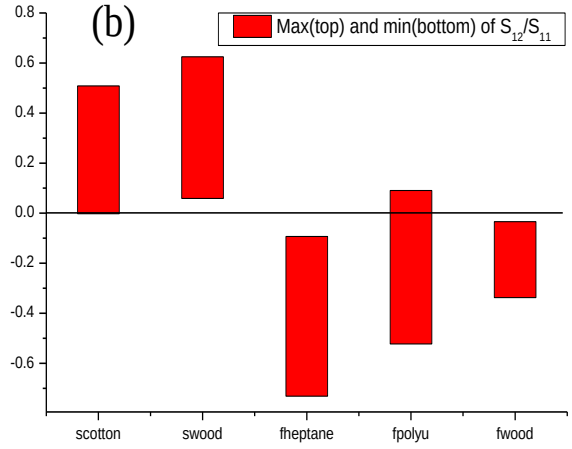
Experimental measurement

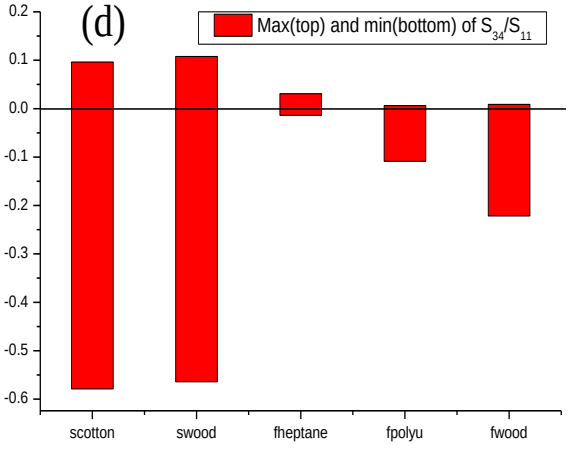
- Scattering of smokes particles different fuels and different combustion conditions







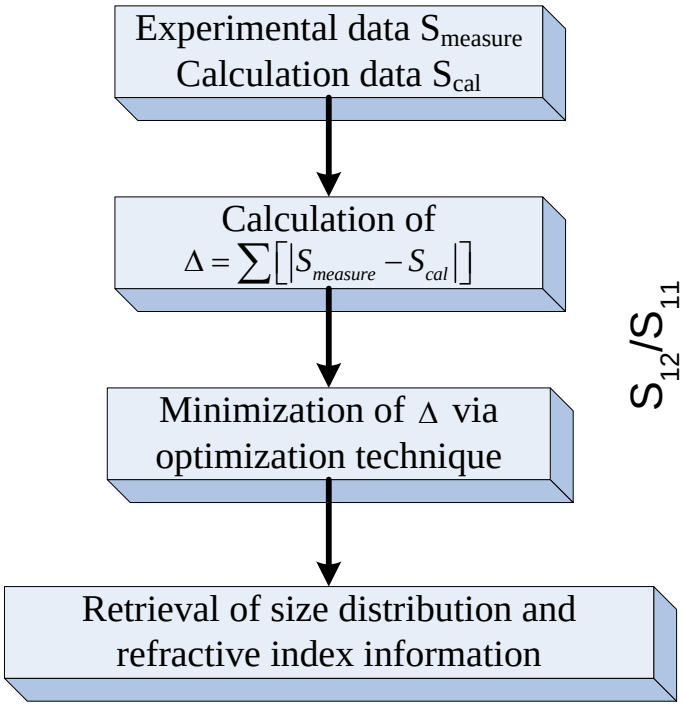


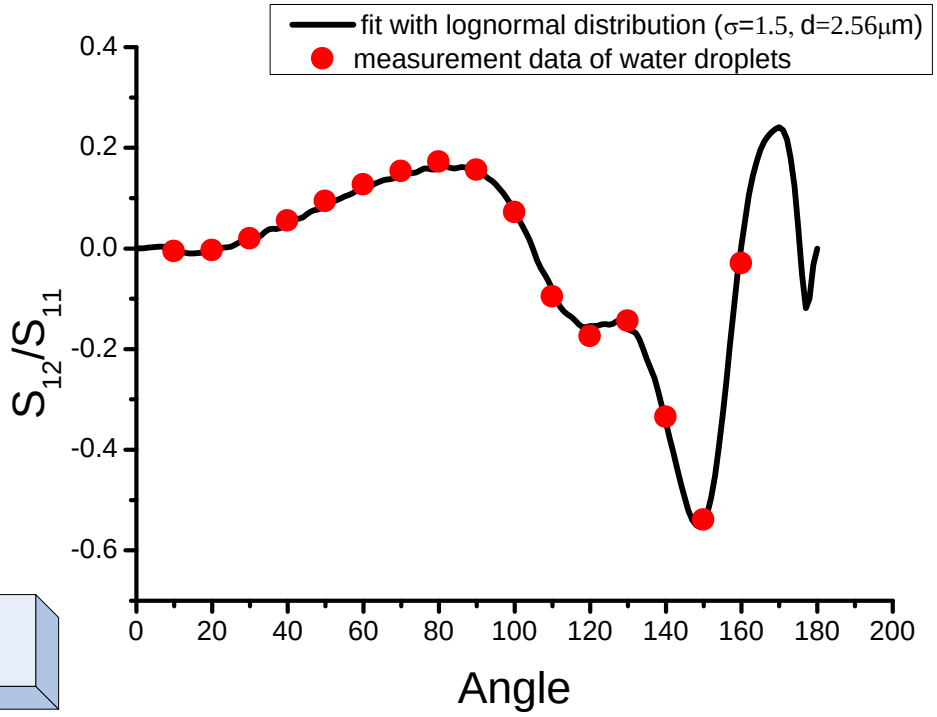


scotton: smouldering cotton
swood: smouldering wood
fwood: flaming wood
firefheptane: flaming n-heptane
fpolyu: flaming polyurethane.

Experimental measurement

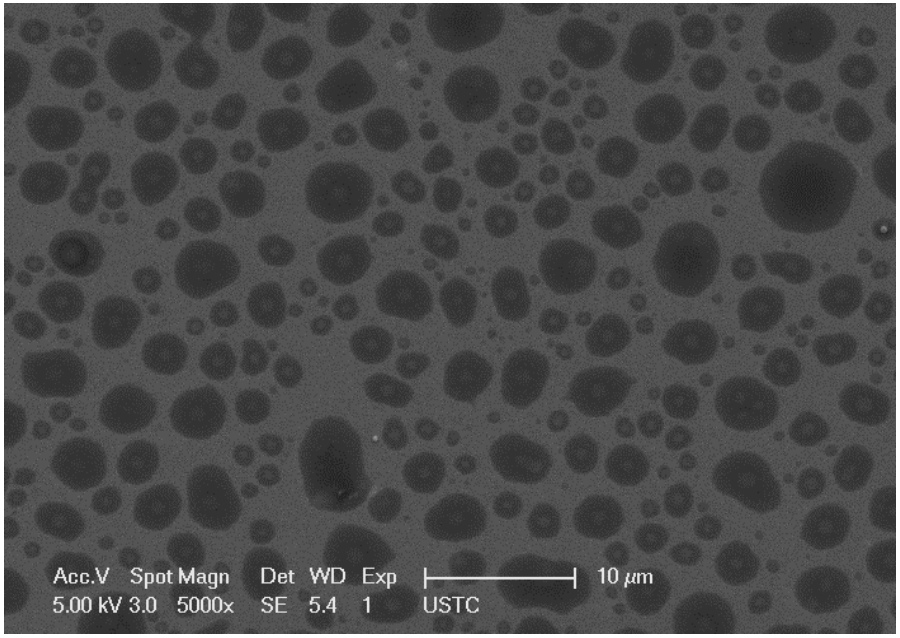
- The retrieval of the size distribution and refractive index of spherical particles

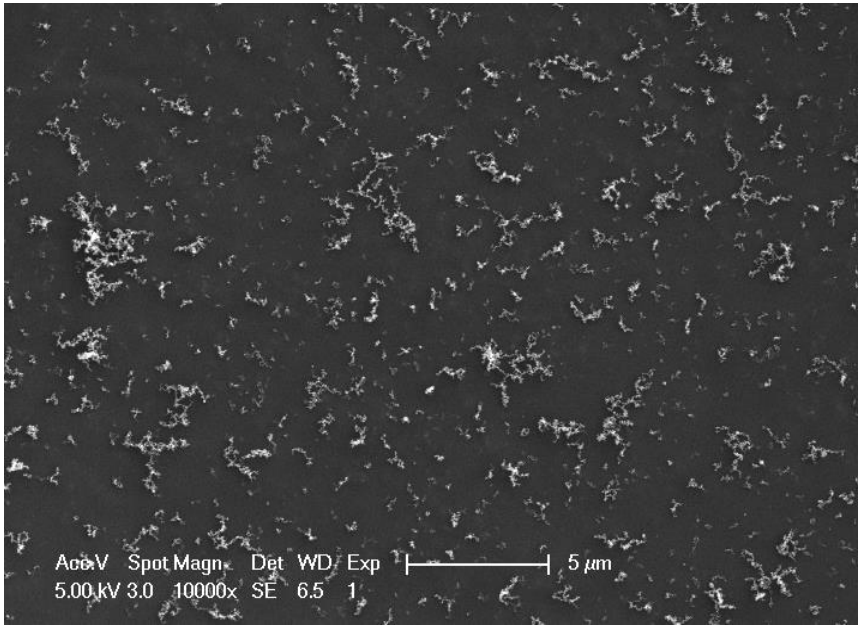




Model study

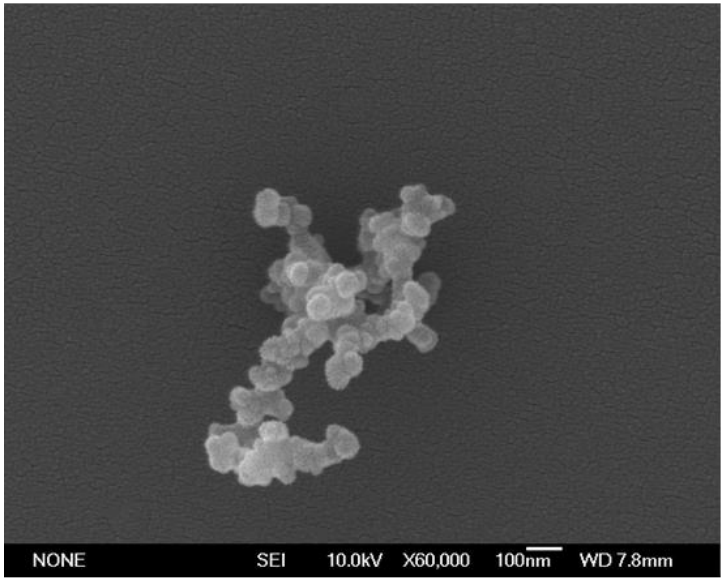
- Image of smoke particulates
  - Smoldering fire (cotton)
  - Flaming fire (n-heptane)



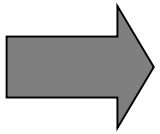


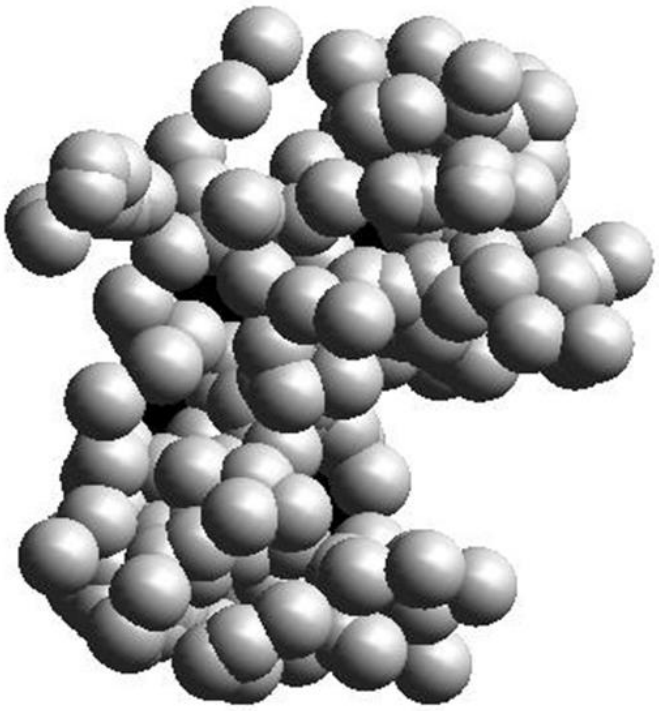
Model study

- Fractal model



SEM Image



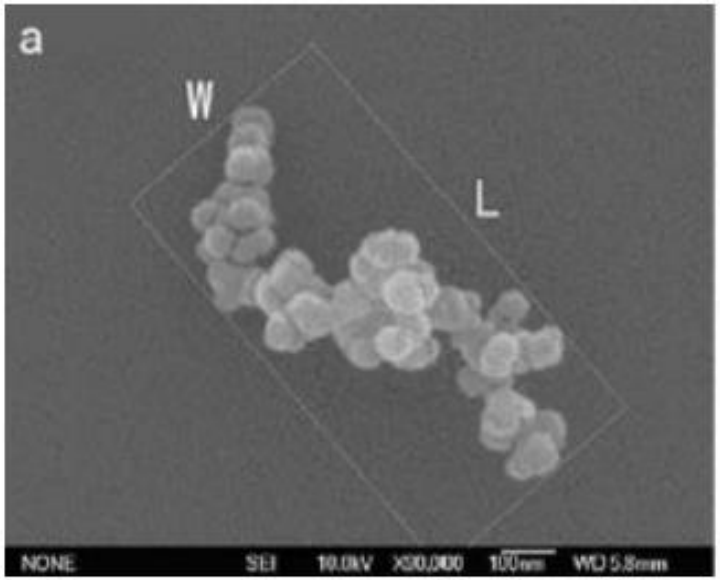


Fractal model

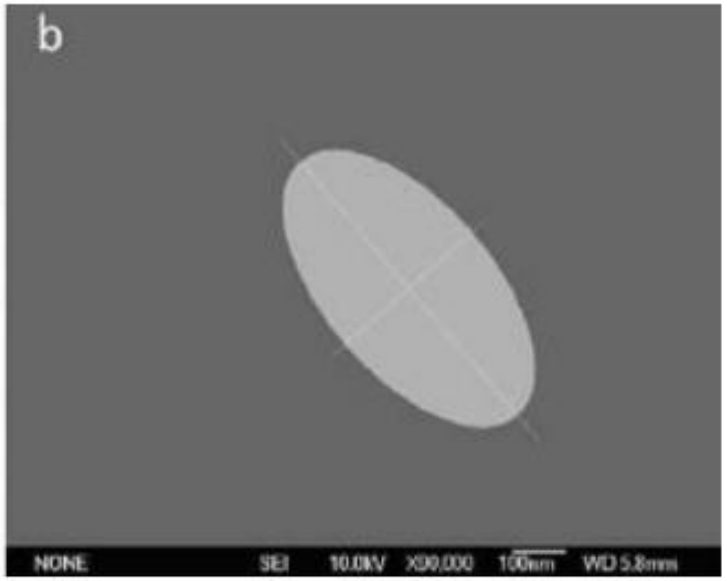
$$N = K_f \left(\frac{R_g}{a} \right)^{D_f}$$

Model study

- ellipsoid model



SEM Image

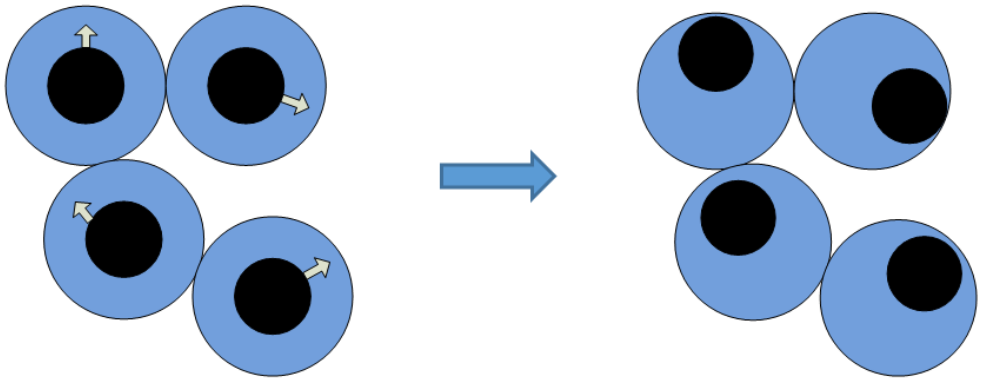


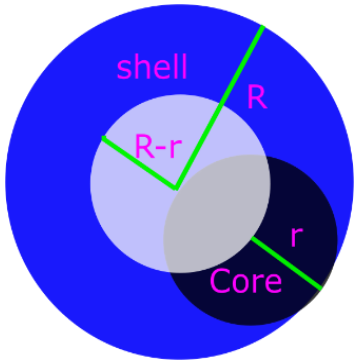
Ellipsoid model

Model study

- Study on optical properties of soot particles mixed with non-absorbing materials

Soot particles thinly coated with non-absorbing aerosols are simulated with acentric monomers model





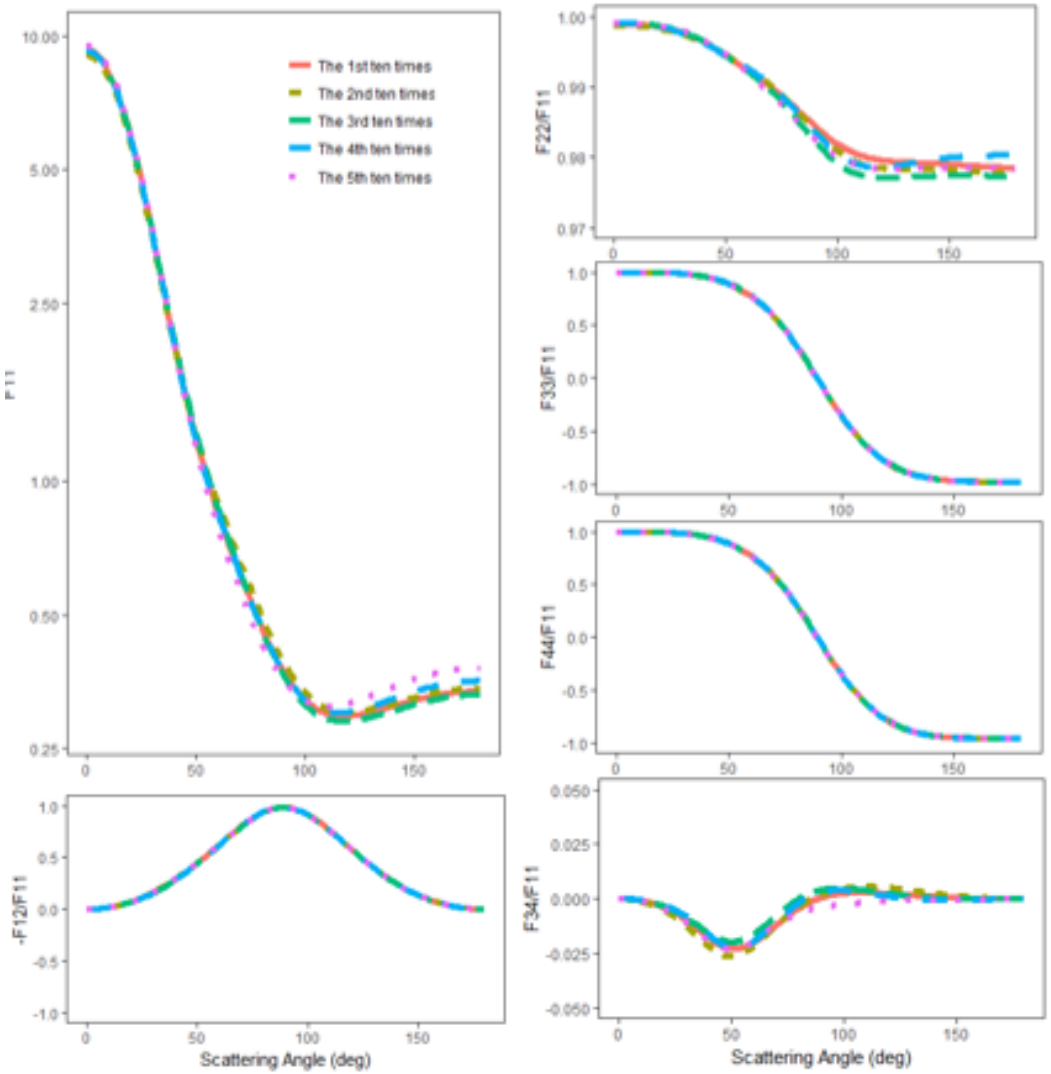
Model study

- The reason of modeling soot particles with acentric monomers model

- In some cases, soot particles are thinly coated, which with nearly core-shell spherical monomers.
- Even though previous studies has proposed more complex DDA model about this shape, but the coatings is difficult to control, so it is difficult to understand how the coatings influence the optical properties.
- The concentric monomers model is simple, but the coatings are not random.

Model study

- Scattering matrices using concentric core-shell model, which are randomly averaged for each 10 calculations

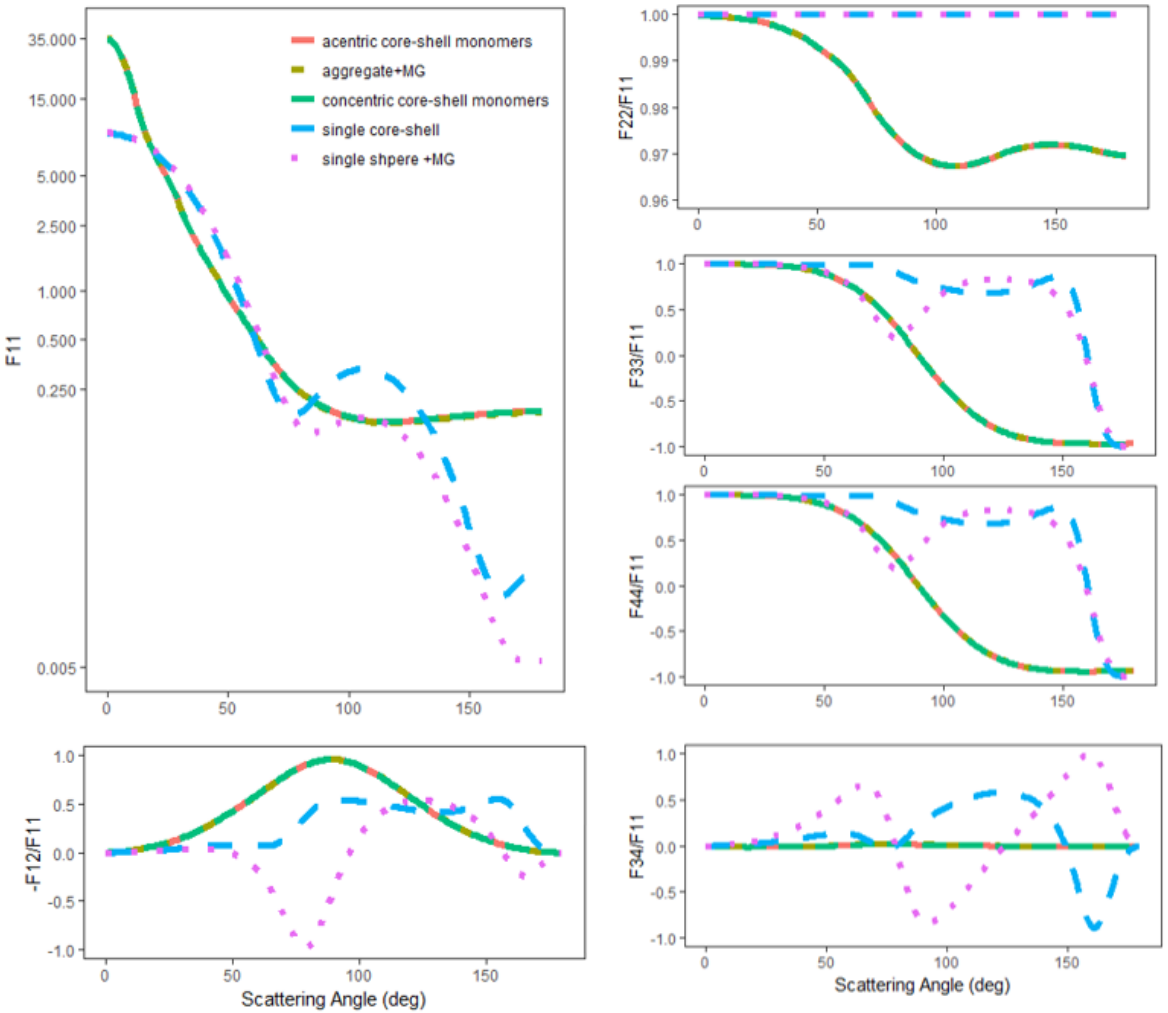


We found the error induced by fractal characteristics with identical parameters can not be eliminated by averaging over ten random realizations.

We generated different models based on the identical fractal aggregates

Model study

- Scattering matrices calculated with different model N_s=300，Df=1.8，r=0.02um，λ=0.55um, Fsoot=0.2

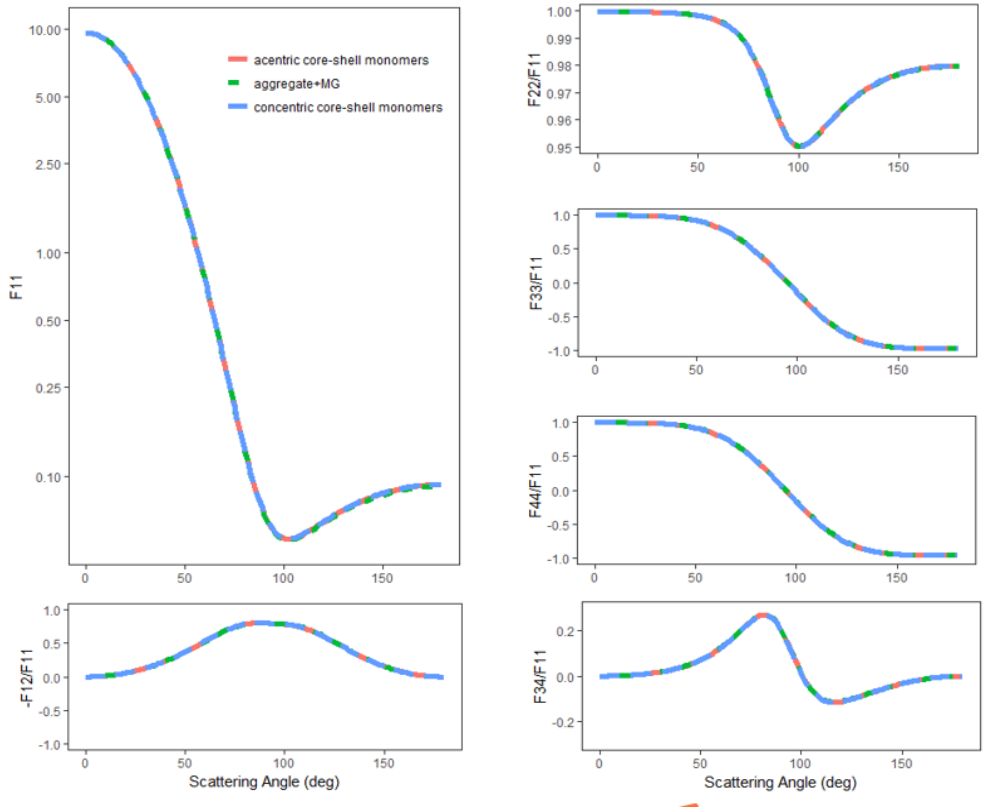


The results calculated using the acentric core-shell monomers model are significantly different from those with single core-shell model and single equivalent sphere model

Extremely closed to those with concentric core-shell monomers model and homogeneous aggregate model

Model study

Scattering matrices calculated using different models N_s=100, $D_f = 2.5$, r=0.02um, $\lambda = 0.55$um, Fsoot $= 0.2$



The results calculated using the three models are also extremely closed in a more compact cases.

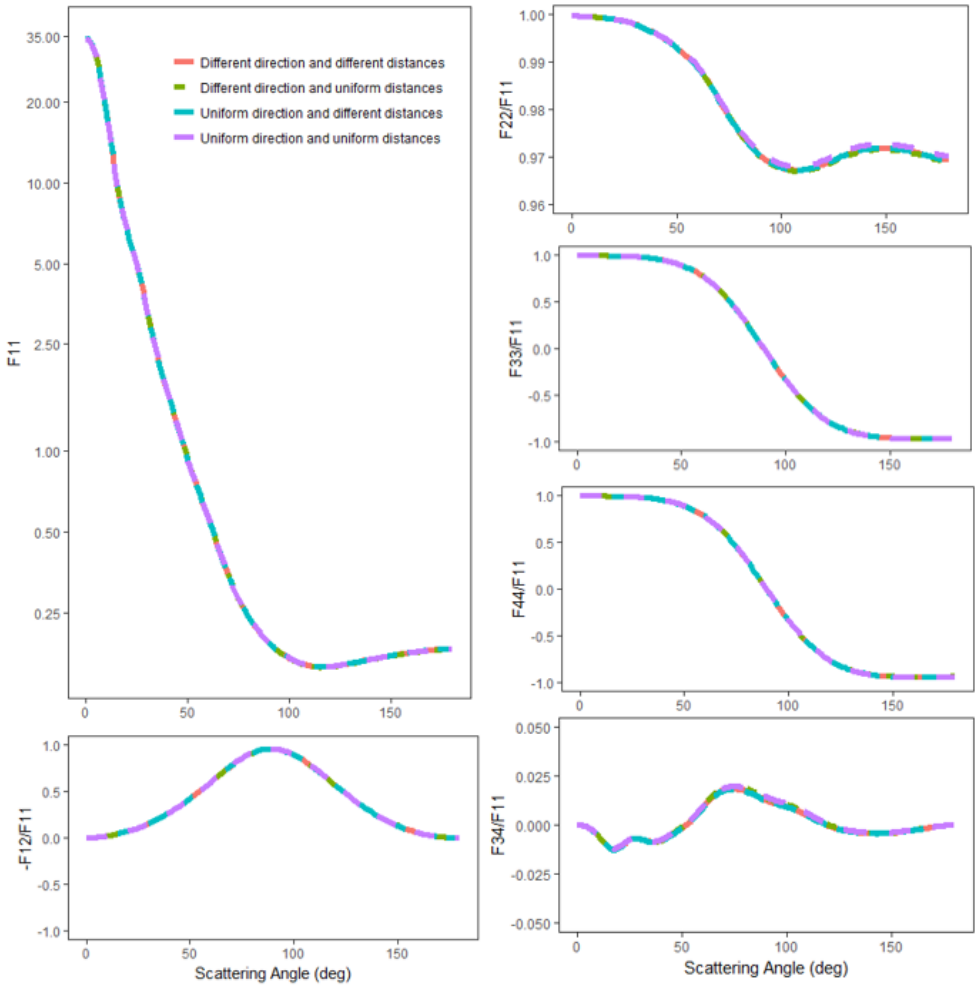
This results are different from previous studies, in which the results of concentric core-shell monomers model and aggregate +MG model are different

The reason may be that the error in previous study may be caused by fractal nature but not model

Model study

Scattering matrices calculated using acentric model with different movement patterns N_s=300， $D_f = 1.8$， r=0.02um， $\lambda = 0.55$um, Fsoot $= 0.2$

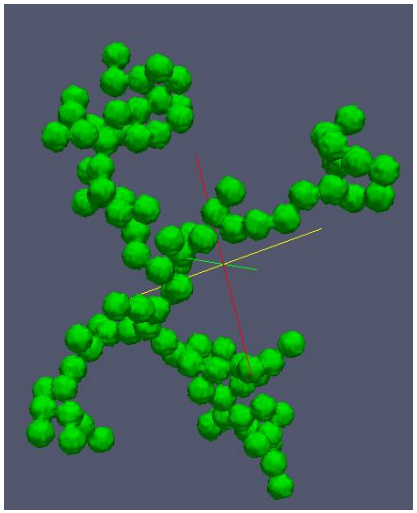
the way how the individual primary particles are coated is unimportant for soot particles with a nearly core-shell monomers

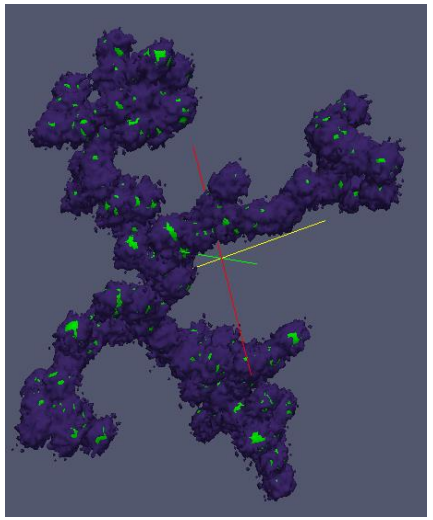


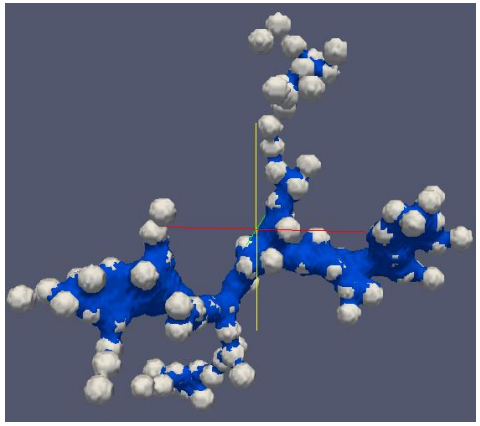
Model study

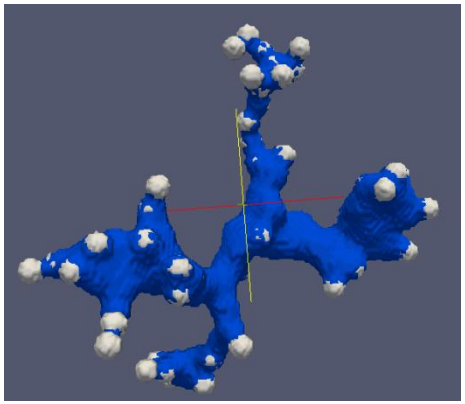
- Works on more realistic models (the codes are written based on previous studies)

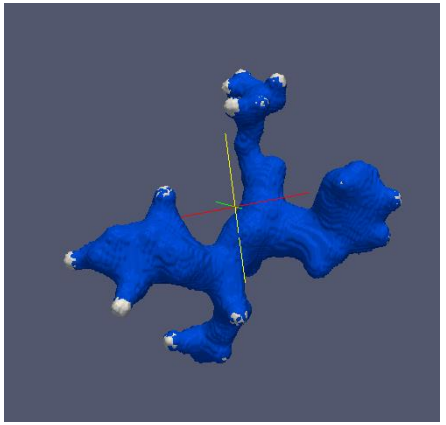
We intend to investigate the optical properties of soot particles with more complex morphology in the future











summary

- We have set up Scattering platform to measure the scattering matrices of smoke particles
- We found the scattering matrices of smoke particles of different fuels are different
- We measured the scattering matrices of smoke particles under different combustion conditions, and found the Mie theory is applicable for smouldering smoke particles, but the flaming smoke particle can be simulated with fractal model
- We conducted image analysis of shape of smoke particulates, and found smouldering smoke particles are nearly spherical. But the flaming smoke particles generally present fractal structure
- We studied the non-spherical model of smoke particles
- We start to study the optical properties of soot particles mixed with non-absorbing materials