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Digital Prototyping of Milk Products

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Motivation

We present models and methods that take steps toward digital prototyping of milk products and other food colloids. The motivation for doing this is the following.
- Digital prototyping has revolutionised the automotive industry by providing designers and engineers with digital models of their products that enable virtual product design, visualisation, and simulation.
- Digital prototyping does not exist in the food industry as the colloidal nature of most foods make them much more challenging to visualise and simulate realistically.
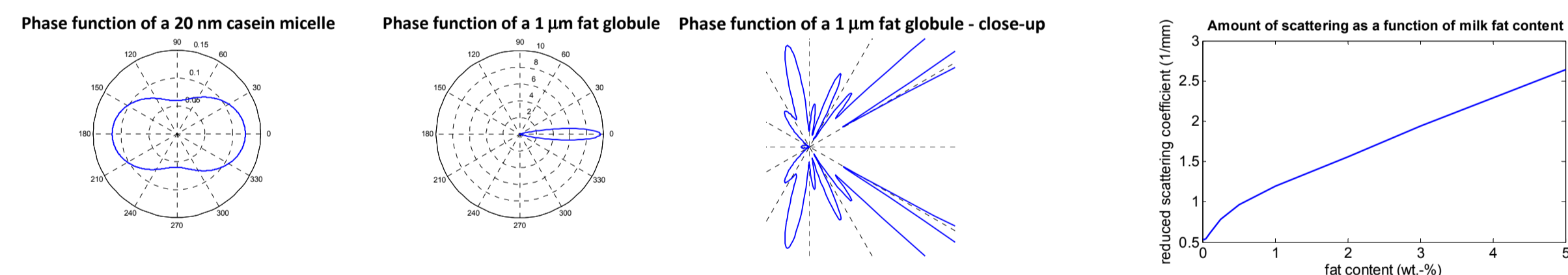
Modelling cow's milk

Milk from an optical point of view [1]:
- Two types of nearly spherical particles: fat globules and casein micelles.
- Host medium with almost the same optical properties as pure water.
- Absorption of vitamin B2 (riboflavin) needs to be added to that of the host medium.
- Refractive indices and size distributions of particle inclusions are given by empirical formulae and measured data.
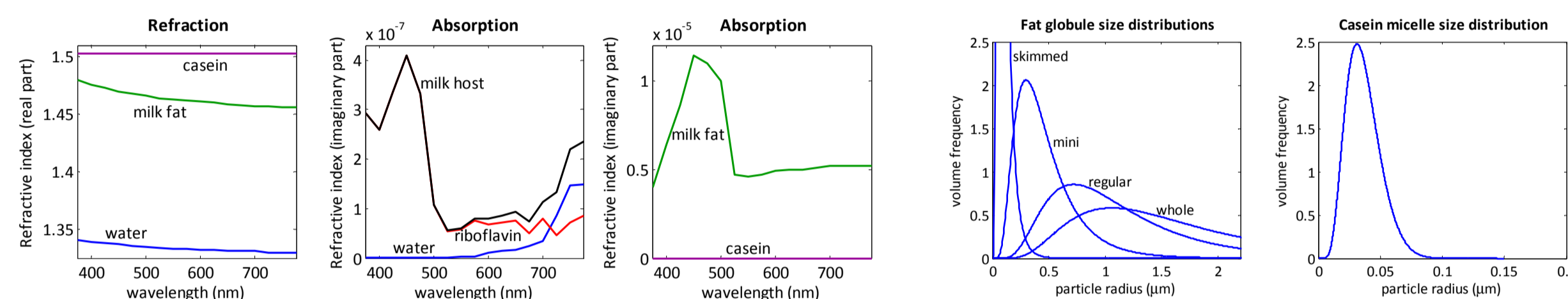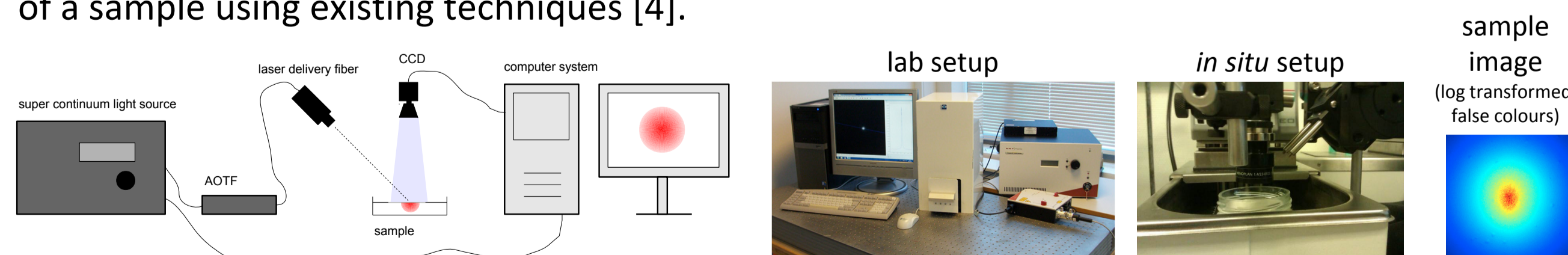

Macroscopic optical properties (absorption coefficient, scattering coefficients, and phase function or asymmetry parameter) are the input needed for a Monte Carlo based graphical rendering. We predict the optical properties of milk as a function of its fat and protein contents using Lorenz-Mie theory with the input specified above [1]. The following plots exemplify our prediction of scattering properties at a wavelength of 650 nm.

Computing appearance and behaviour

The mathematical model of radiative transfer is used for rendering realistic images. We solve the radiative transfer equation using Monte Carlo path tracing [1], which is a sampling-based rendering algorithm that works in general (see illustration to the right).

Using our milk model and rendering method, we are able to show the visual significance of each component in the milk.
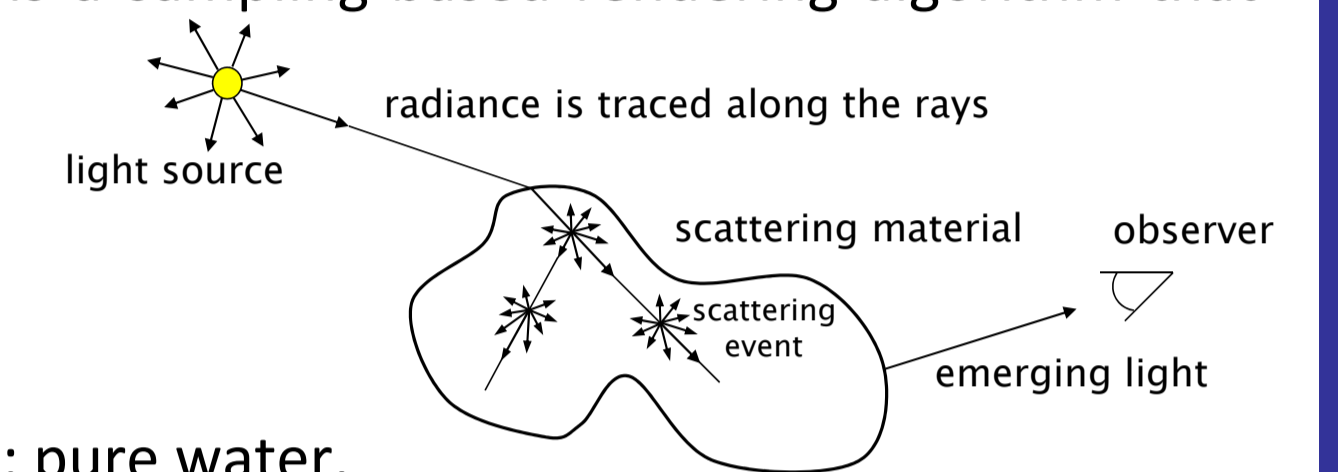
In the rendered image below, the glasses contain (left to right): pure water, milk host, casein micelles in water, fat globules in water, skimmed milk, regular milk, and whole milk [1].

We can also add cocoa particles to render the appearance of chocolate milk.

To simulate the dynamics of liquid products that only exist digitally, we use deformable simplicial complexes with an optimisation-based finite element method [2]. The following sequence of images is an example.

Measuring scattering properties

We capture images of laser at different wavelengths incident on a sample *in situ*. The wavelength of the laser is easily adjustable as we use an NKT Photonics SuperK laser [3]. This enables us to retrieve spatially and spectrally resolved diffuse reflectance images. We also acquire images with the laser at several angles of incidence to enable oblique-incidence reflectometry. With this setup (see below), we can estimate the macroscopic optical properties of a sample using existing techniques [4].

Validation

To find out if our model correctly predicts the appearance of real milk, we model our experimental setup digitally. Tests at a wavelength of 650 nm is provided in the figures above. These illustrate that our milk model and Monte Carlo simulation can predict the outcome of our diffuse reflectance image captures.

Finally, we would like to validate our milk model by comparison of measured and predicted scattering properties. This work is, however, not yet finished as our measurement technique is in the process of being calibrated using phantom materials. The figure to the right indicates preliminary results.

References

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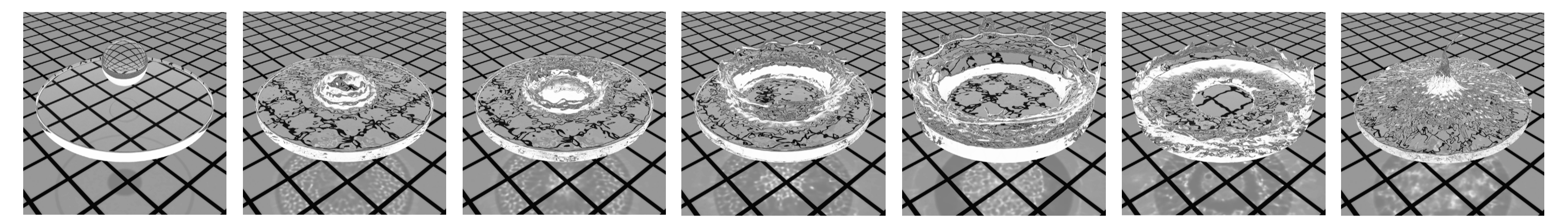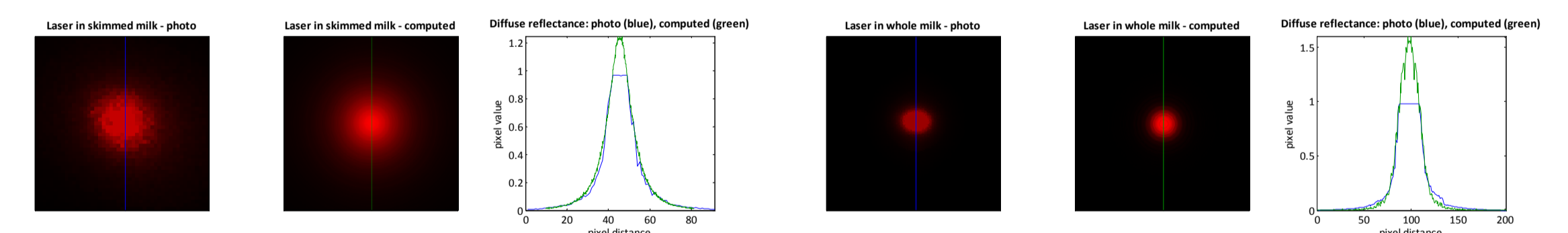
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