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Spatio-temporal scaling laws in a heated egg yolk

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Denaturation, aggregation and gelation of proteins and lipids are biologically relevant out-of equilibrium processes which are coupled by a hierarchy of length, time and energy scales. Finding the characteristic scaling laws governing these processes on the relevant time and length scales is necessary to predict the changes of biomolecules to future time scales.

Here, we use heated egg yolk as a model system to reveal the spatio-temporal relationships underlying these intricate processes for a wide range of time and temperature combinations [1]. Using low-dose X-ray photon correlation spectroscopy (beamline P10 at PETRA III, Hamburg, Germany) in ultra-small angle X-ray scattering geometry, we follow the time-resolved structural and dynamical evolution of multiple non-equilibrium processes occurring in a heated hen egg yolk. Following key structural and dynamical features, we identify non-equilibrium processes such as denaturation and aggregation of proteins, protein gelation, gel ageing, two-step aggregation of yolk low-density lipoproteins (LDLs), and gelation of yolk granules. We find that the overall kinetics and dynamics governing protein denaturation, aggregation, and gelation follow Arrhenius-type time-temperature superposition (TTS). This implies an identical mechanism underlying these consecutive processes, with a temperature-dependent reaction rate. At high temperatures, TTS breaks down during gelation and temperature-independent gelation dynamics is observed. This indeed reflects the complex association of protein aggregates that results in a gel network. In a broader sense, our research [1] provides an illustration of how to comprehend the fascinating non-equilibrium events in inherently complex, multi-component, thermally driven biological systems on length scales ranging from nanometers to micrometers in a time spectrum of milli-seconds to hours.

References:

- [1] Anthuparambil, N.D., Girelli, A., Timmermann, S. et al. Exploring non-equilibrium processes and spatio-temporal scaling laws in heated egg yolk using coherent X-rays. **Nat. Comm.** 14, 5580 (2023). <https://doi.org/10.1038/s41467-023-41202-z>

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