Multi speckle dynamic light scattering of swimming bacteria

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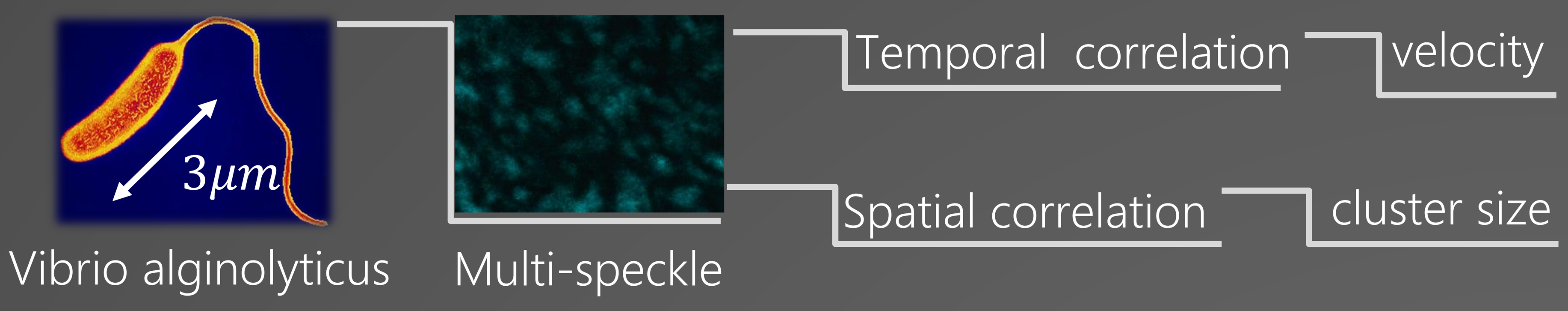
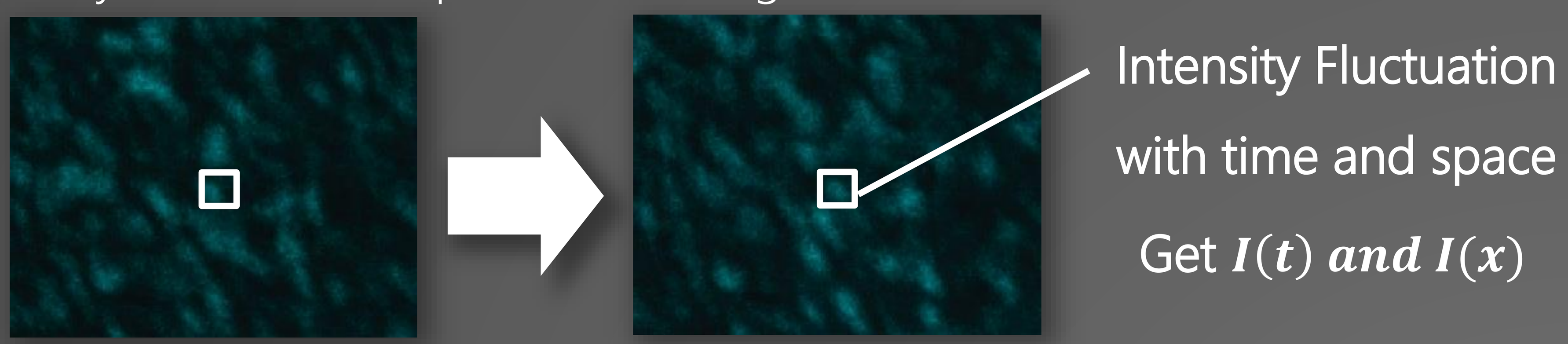
Introduction

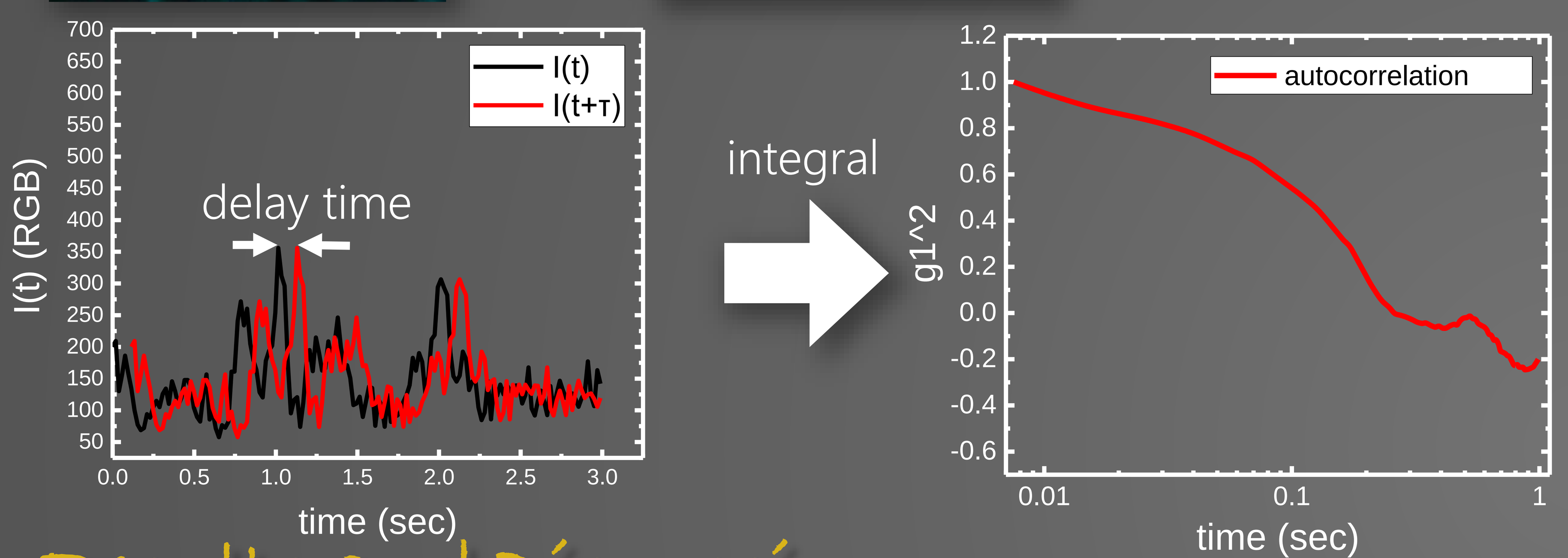
Traditional dynamic light scattering (DLS) is one method to find out the diffusion dynamics of passive particles. However, DLS can only measure the temporal correlation without the spatial dynamics of the active particle. In this work, we try to measure the spatial dynamics of collective motion of bacterial behavior by the simple optical method. It is applied to get scattering multi-speckles on CCD. These speckles shine due to the motion of bacteria. Thus, spatial correlation can be analyzed by these shining speckles. Comparing the DLS, how does multi-speckle dynamic light scattering measure spatial correlation?



Method

- Dynamical multi-speckles are caught with CCD





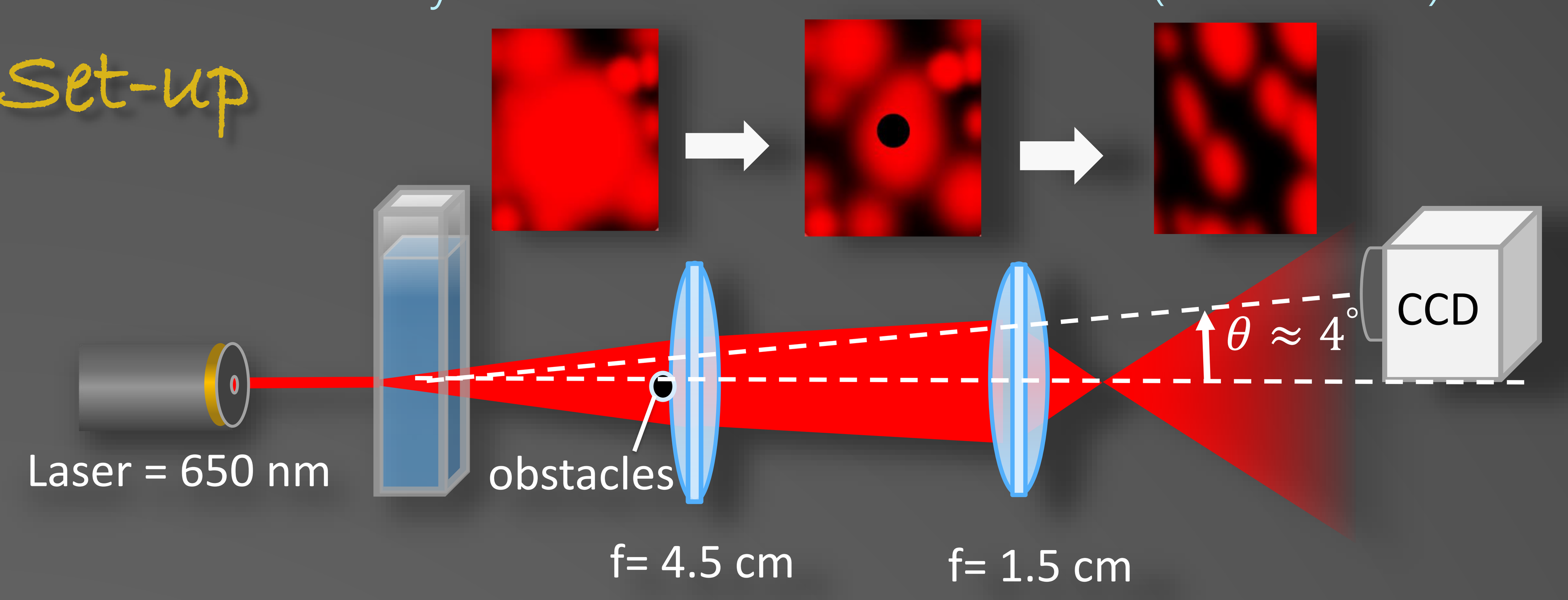
Motivation

Find the new optical method of multi-speckle to execute analysis below :

1. Temporal correlation
   - How Na^+ and time passing affect swimming velocity ?
2. Spatial correlation
   - How Na^+ and time passing affect speckle size ?

- relation of velocity and collective motion behavior (cluster size)

Set-up



1. Temporary correlation

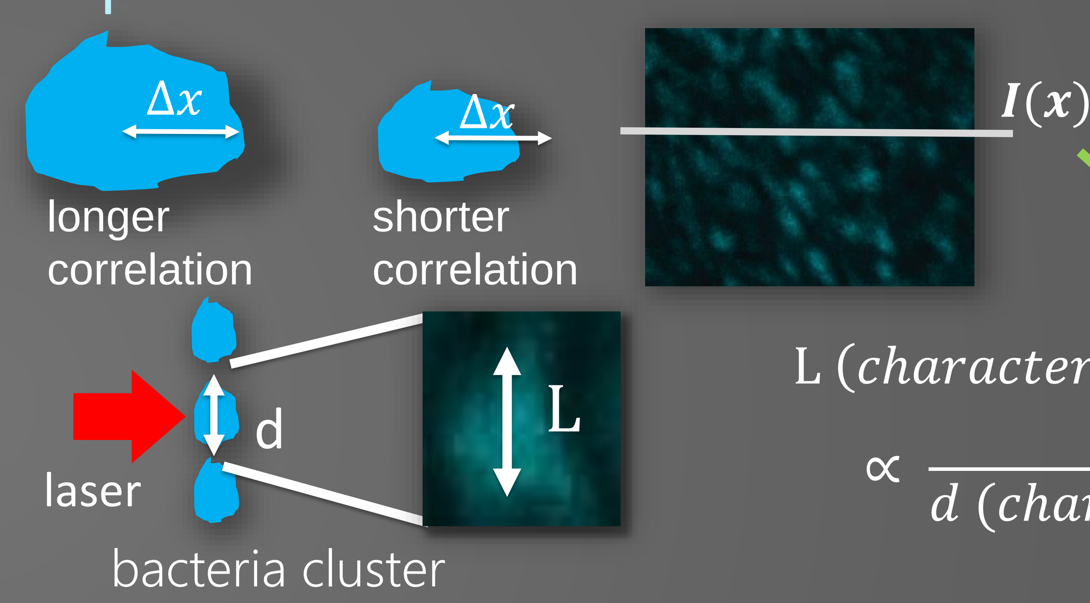
$$g_2(\tau) = \int \frac{< I(t)I(t+\tau) >}{< I(t) >< I(t+\tau) >} dt \;, \qquad g_2(\tau) = 1 + Bg_1^2(\tau)$$

$$g_1(t) \approx e^{-\gamma\tau}, \qquad \gamma = q^2 D \;, \qquad q = \frac{4\pi n}{\lambda}\sin(\frac{\theta}{2})$$

- Diffusion constant → the mean velocity

$$< R^2 > = 6Dt \;, < V > = \sqrt{6D}$$

2. Spatial correlation

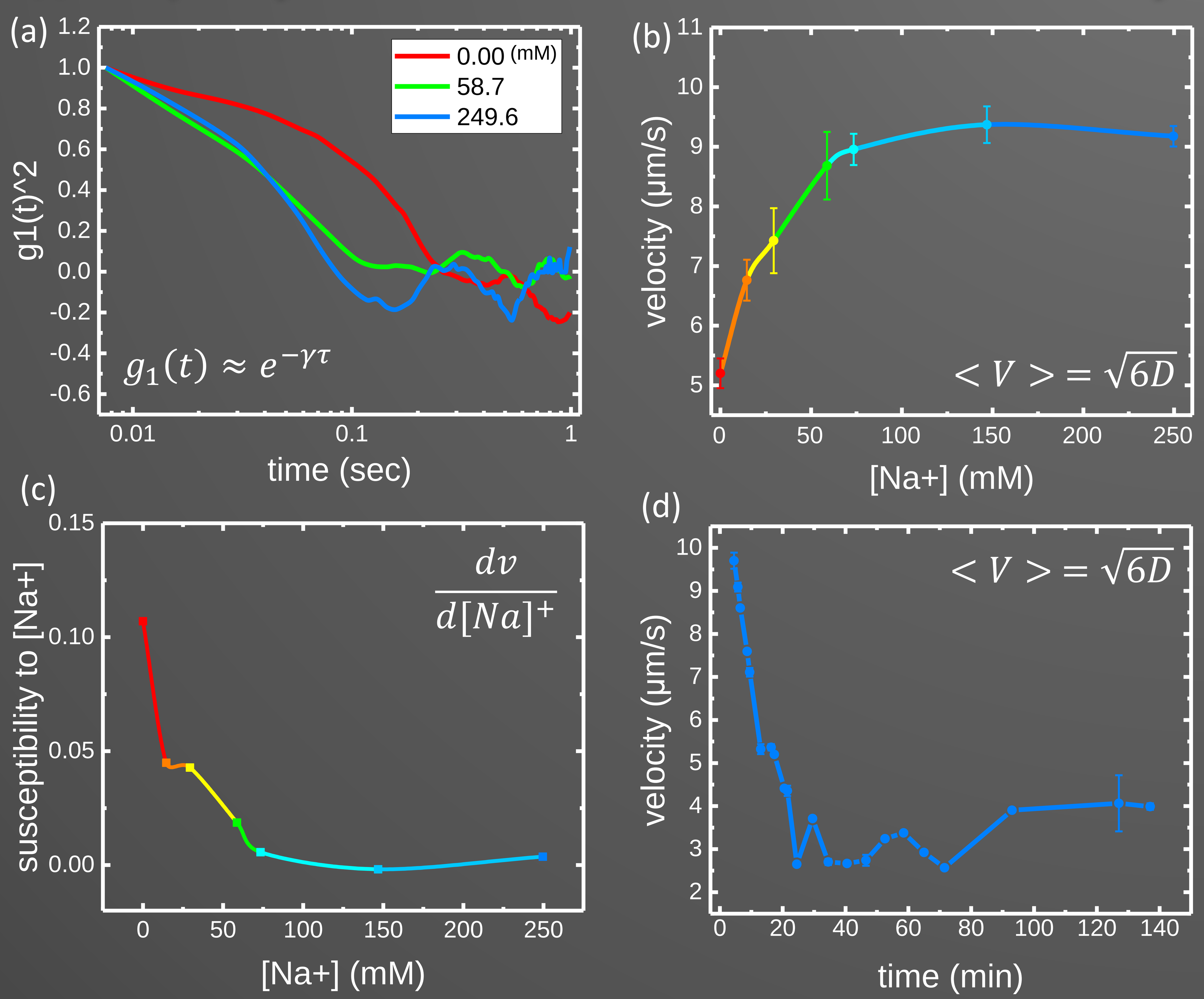


$$g_1(x) \approx e^{-\frac{x}{L}}$$

$$L\ (characteristic\ speckle\ size) \propto \frac{1}{d\ (characteristic\ cluster\ size)}$$

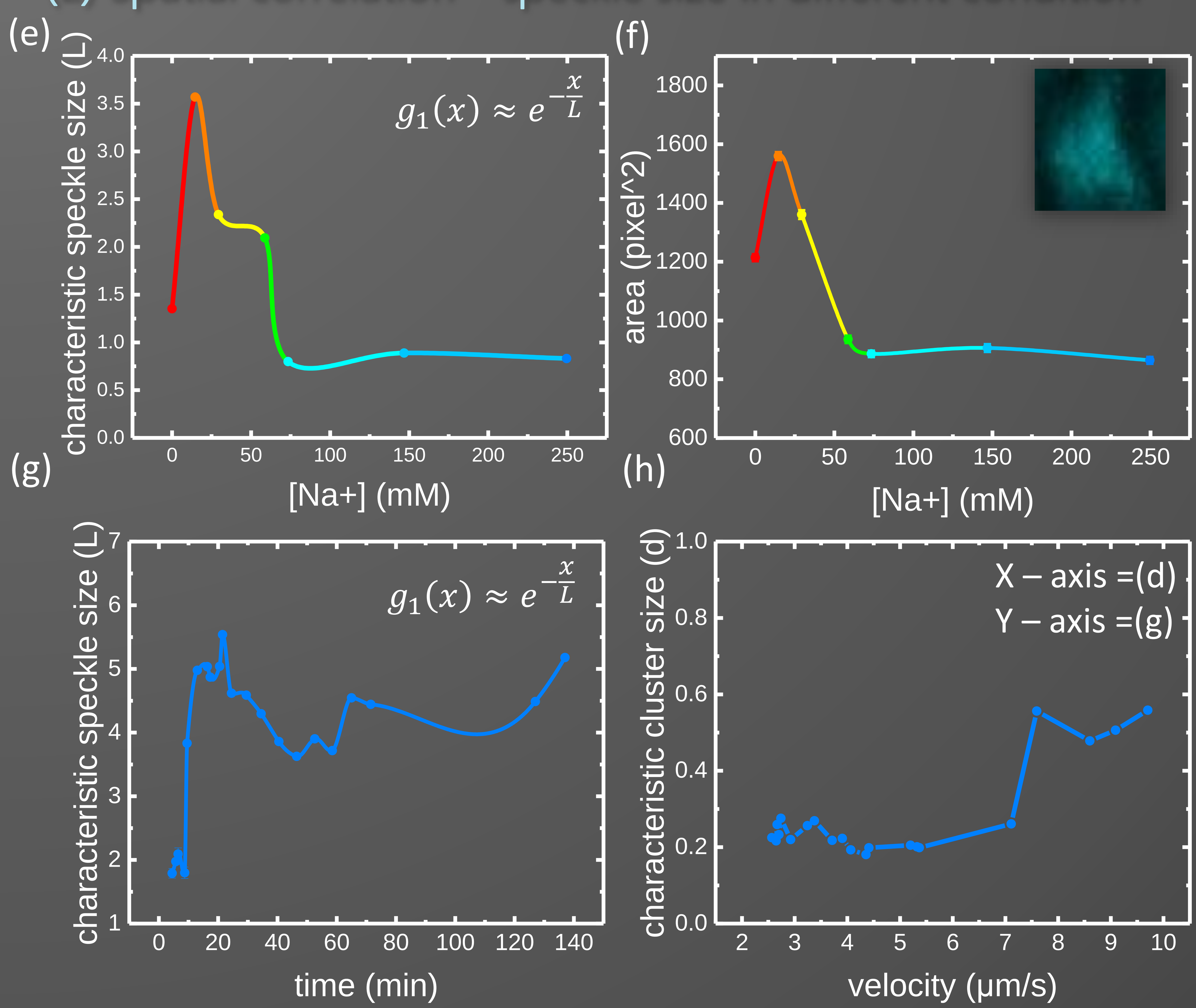
Results and Discussion

(1) Temporary correlation – Na^+ concentration and mobility



- (a) autocorrelation decays faster with higher Na^+ concentration
- (b) velocity increases dramatically at first, and smoothly subsequently
- (c) with VAR(v) of (b), susceptibility decays with Na^+concentration
- (d) mobility decays with time, but increases a little after 60min

(2) Spatial correlation – speckle size in different condition



- (e) find speckle size according to decay constant
- (f) measure speckle size artificially, whose tendency is similar to (e)
- (g) speckle size increase with time
- (h) use the result of (d) and (g),cluster size increases as velocity higher, increases dramatically in $v \approx 6{\sim}9\ \mu m/s$

Summary

Comparing to DLS, multi-speckle can be measured with our optical method.
Multi-speckle tells us spatial information about collective motion of bacteria.

Time analysis (dynamics)

- Na^+ to velocity increases dramatically at first, and smoothly afterward
- mobility decays with time, but increases a little after 60min

Spatial analysis (speckle size)

- cluster size is bigger at higher velocity, and increases dramatically at $v \approx 6{\sim}9\ \mu m/s$

Reference

- Multispeckle diffusing-wave spectroscopy CRPP, CNRS, avenue Albert Schweitzer, F-33600 Pessac, France
- Adaptive Speckle Imaging Interferometry L. Brunel, A. Brun1, P. Snabre , L. Cipelletti