

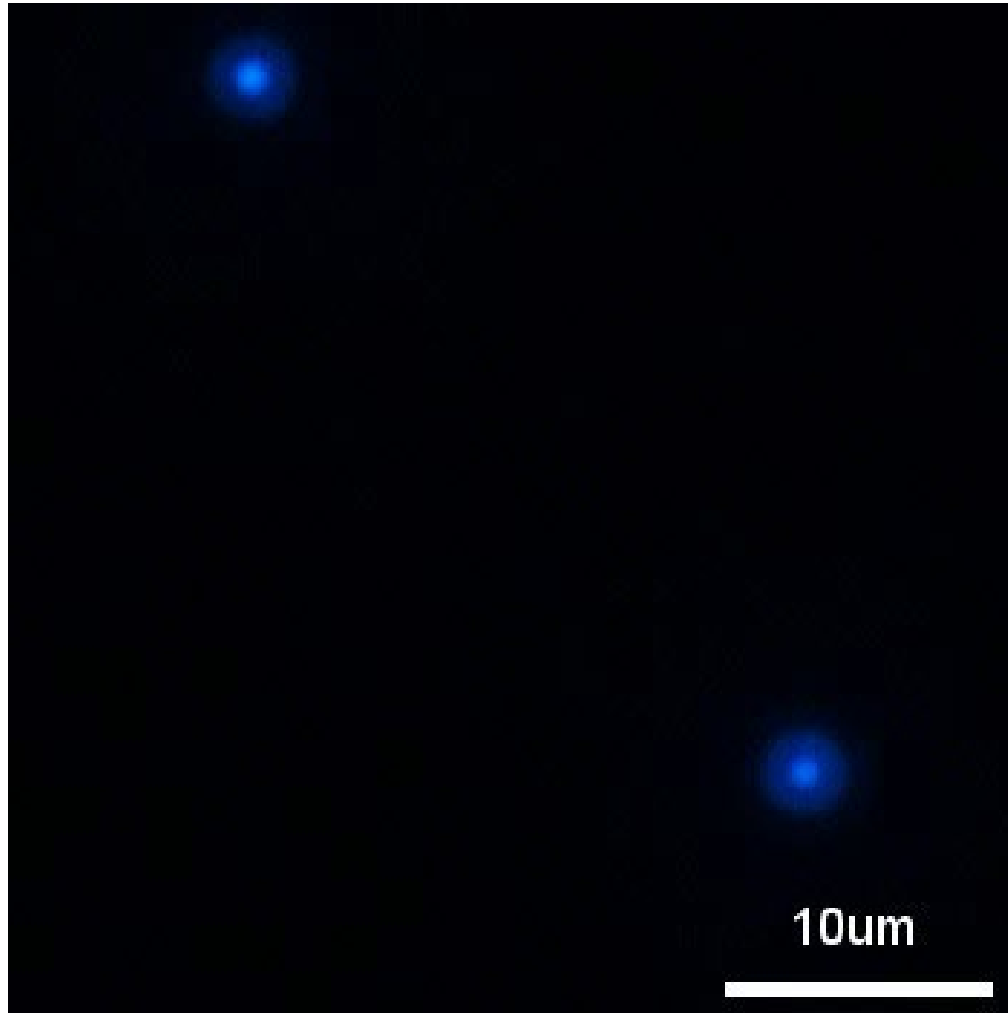
2019.11.21  
物性物理学C

# ランジュバン方程式

北 畑 裕 之

# ブラウン運動

ナノ粒子



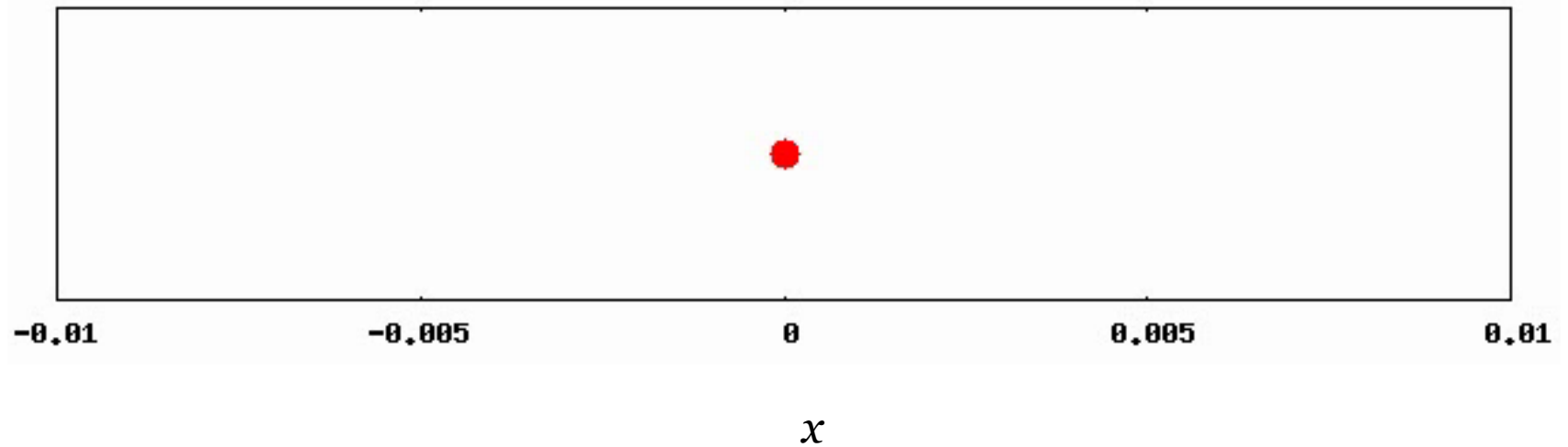
# Langevin方程式

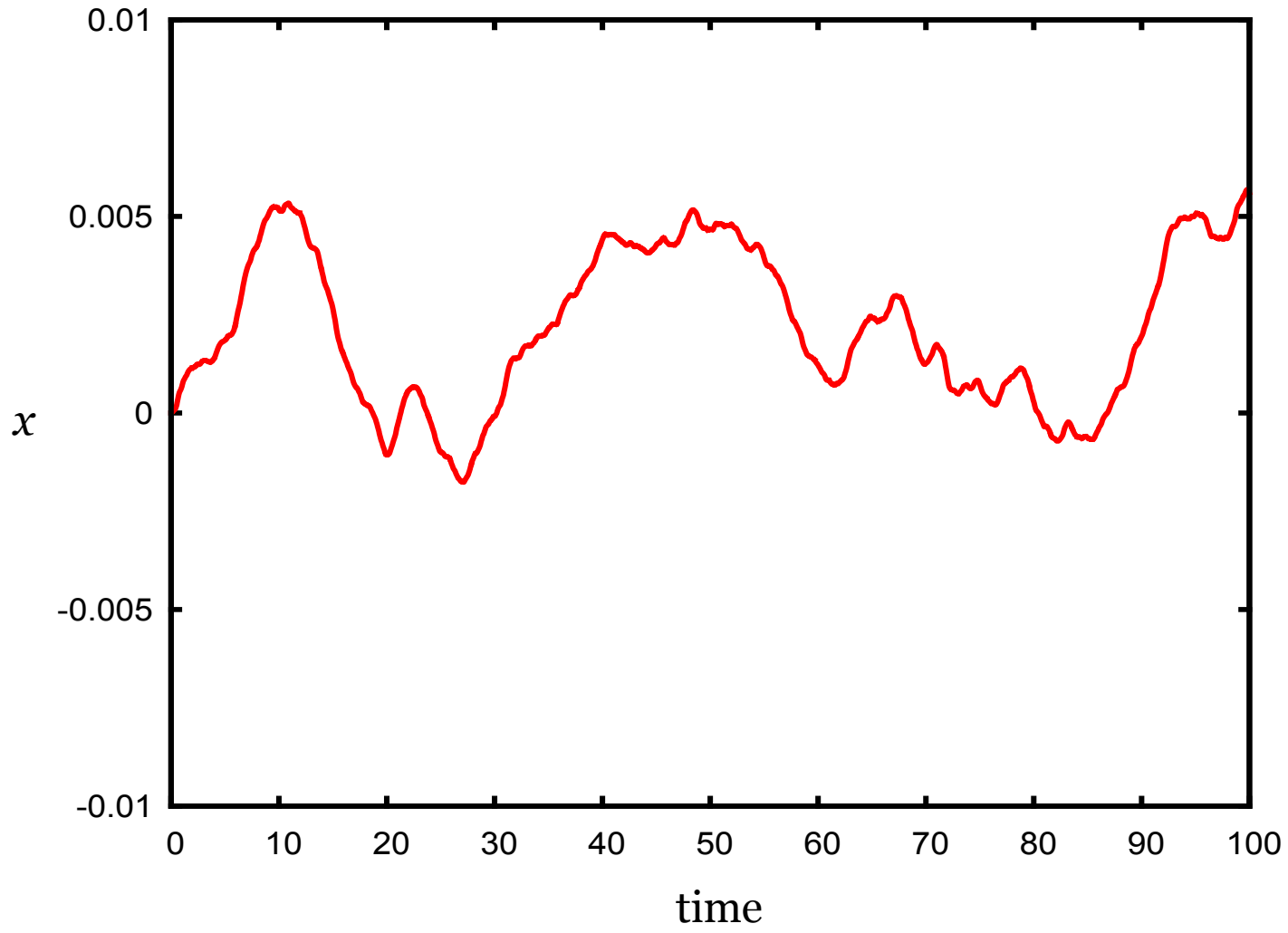
$$m \frac{d^2 \mathbf{r}}{dt^2} = -\gamma \frac{d\mathbf{r}}{dt} + \boldsymbol{\xi}(t)$$

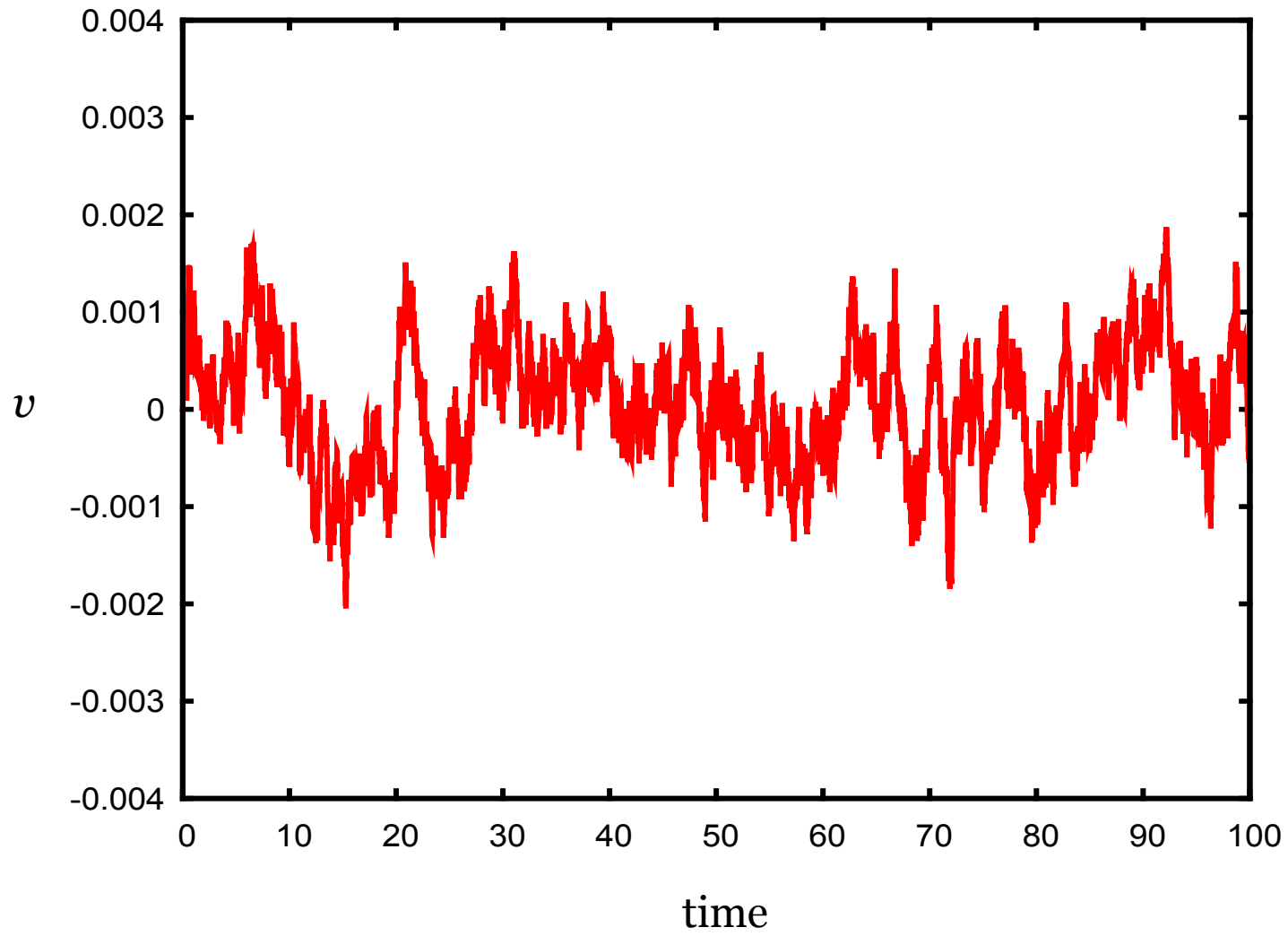
$$\langle \boldsymbol{\xi}(t) \rangle = 0$$

$$\langle \boldsymbol{\xi}(t) \cdot \boldsymbol{\xi}(s) \rangle = 2M\delta(t-s)$$

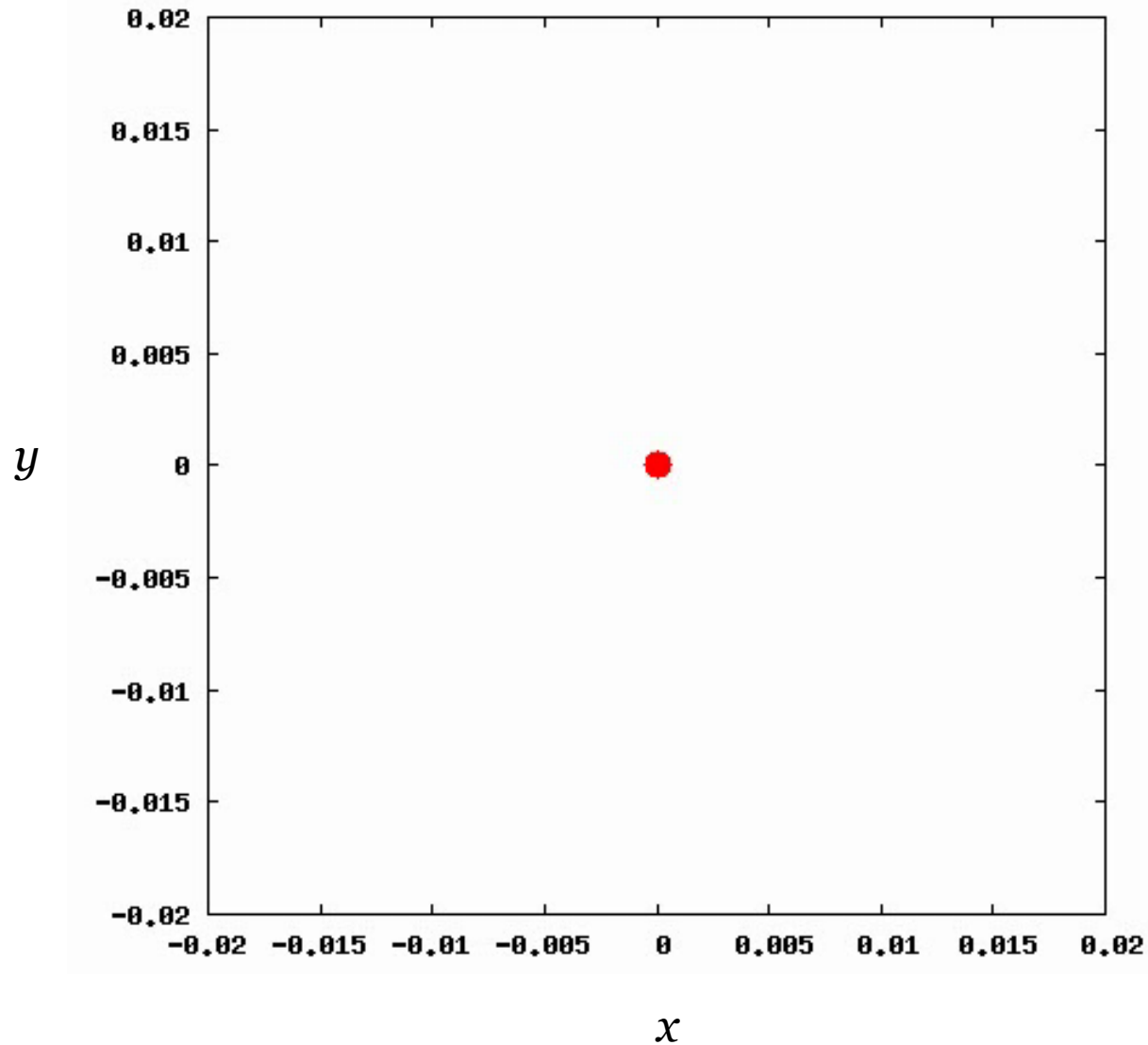
# 1次元系でのLangevin方程式による挙動



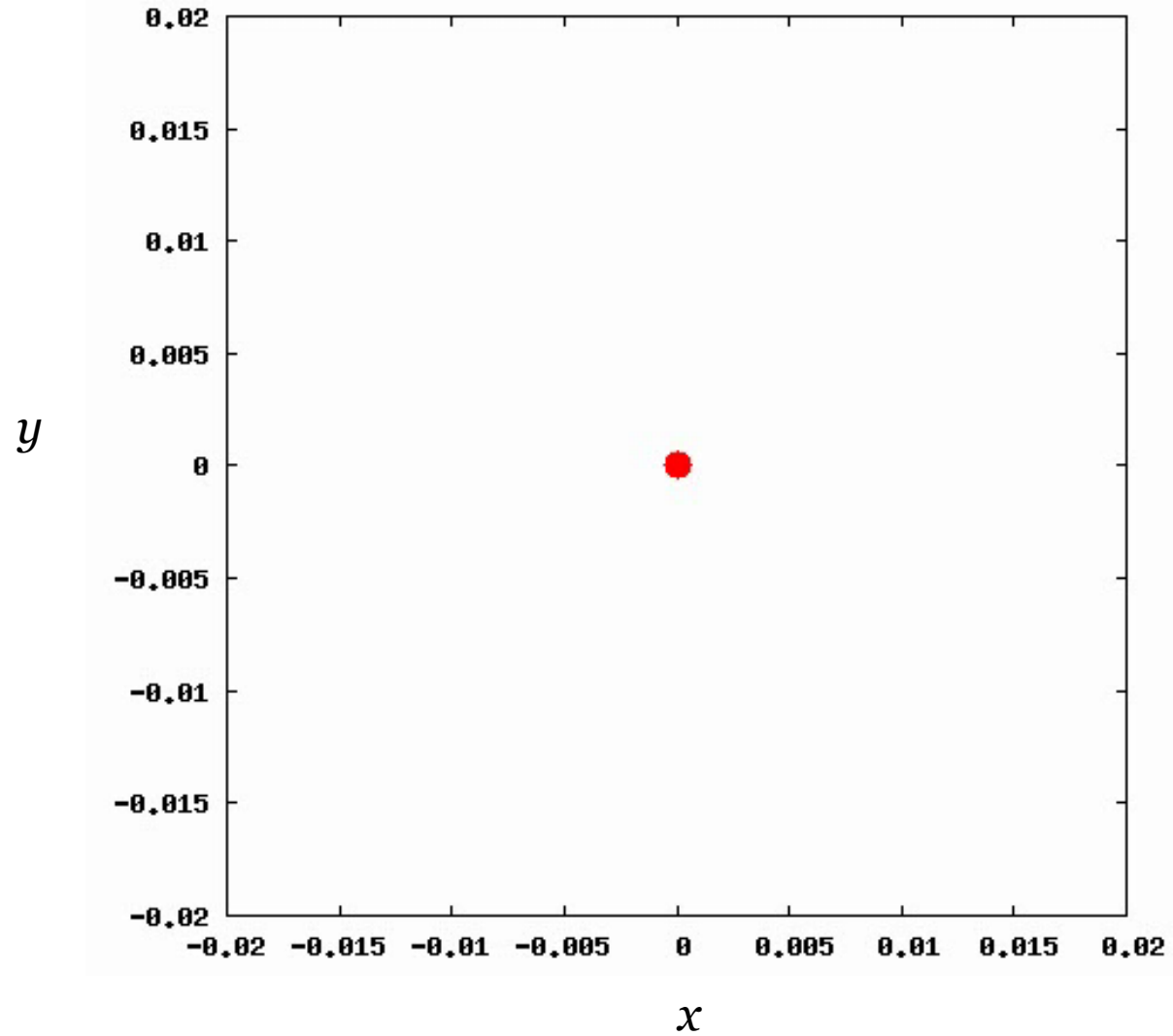




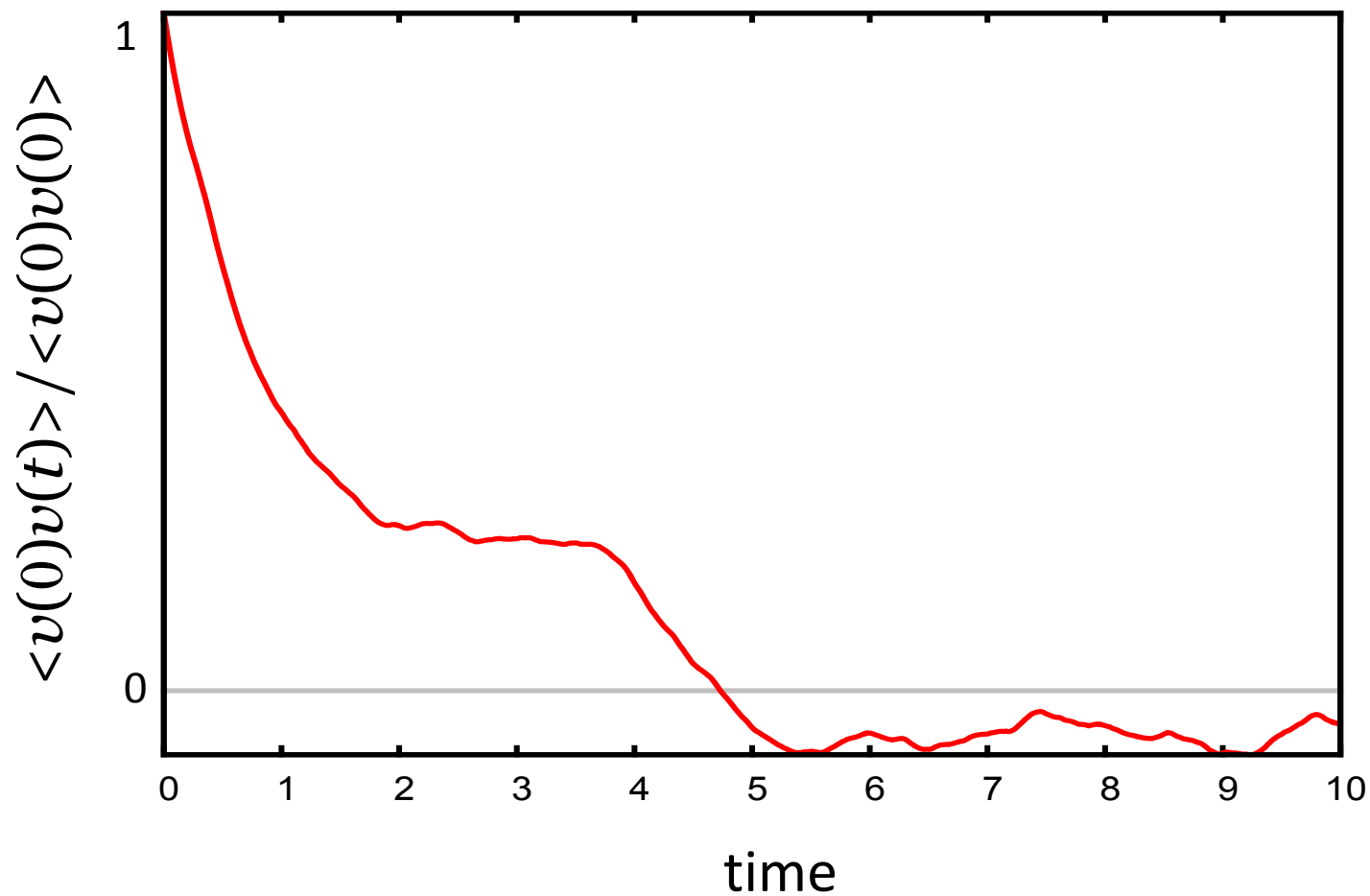
# 2次元での数値計算



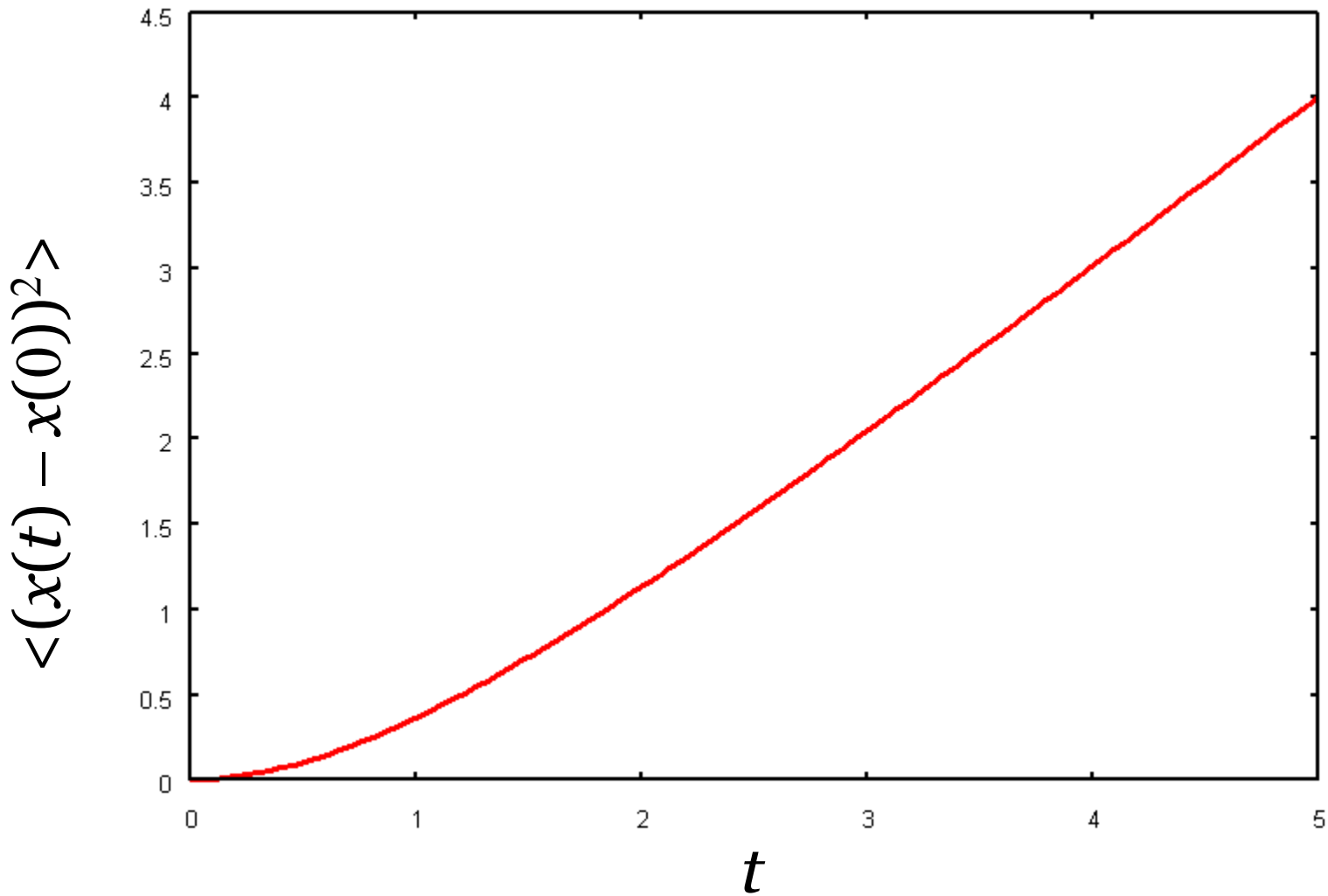
軌跡を残すと







$$\langle v(0)v(t) \rangle / \langle v(0)v(0) \rangle \propto \exp(-t/\tau)$$



$$\left\langle (x(t) - x(0))^2 \right\rangle = \frac{2M}{\gamma^2} \left[ t + \frac{m}{\gamma} \left( e^{-\frac{\gamma}{m}t} - 1 \right) \right]$$