Reports on my projects in 4S/4A semester

M1 Hiroki Fujimoto

Apr. 22 @Midterm report

Contents

Long

- Part 1：Experimental research @Higuchi Lab

  Measuring the force exerted by a myosin in a plant cell with optical tweezers
  (光ピンセットを用いた植物細胞内でのミオシンの力測定)

Very short

- Self Introduction

Short

- Part 2：Seminar in theoretical physics @Yoshida Lab

  Analyzing stellar spectra with machine learning
  (機械学習による天体スペクトルの解析)

Part 1

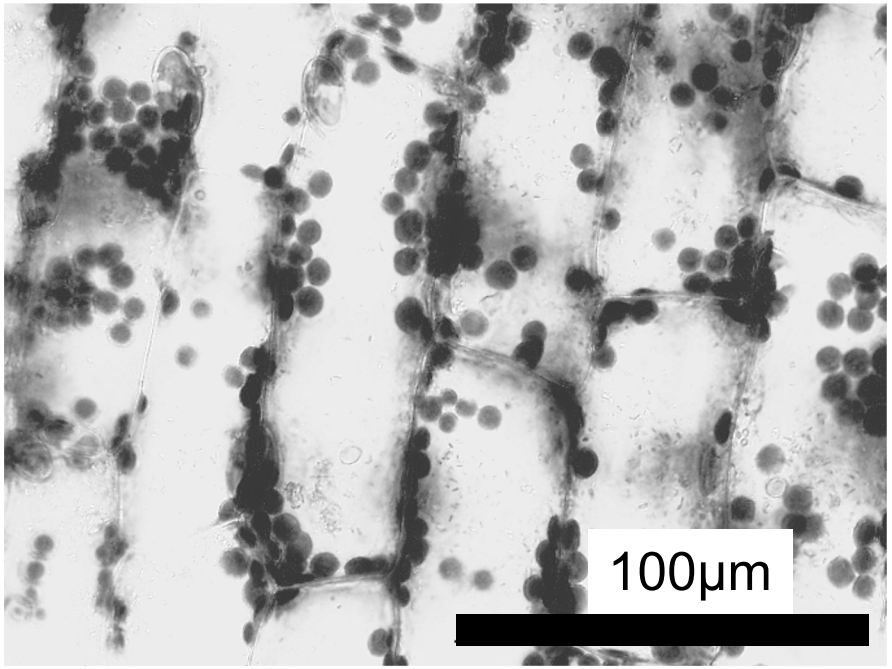
Measuring the force exerted by a myosin in a plant cell with optical tweezers

Contents of Part 1

- What is myosin? What is optical tweezers?
- Outline of experiments
- Microscope and optical tweezers
- Experiment 1:
  Measurement of the spring constant of optical tweezers
- Experiment 2:
  Measurement of the force exerted by a myosin

What is myosin?

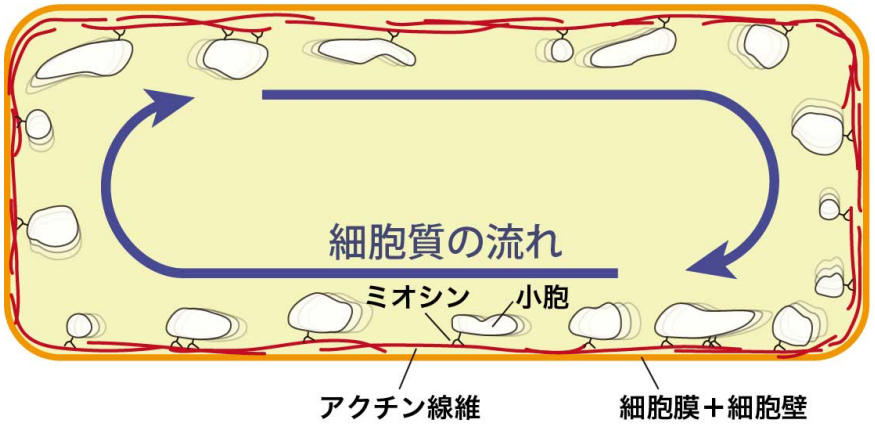
We can see chloroplasts(葉緑体) moving in plant cells.
This is called “Cytoplasmic streaming”.



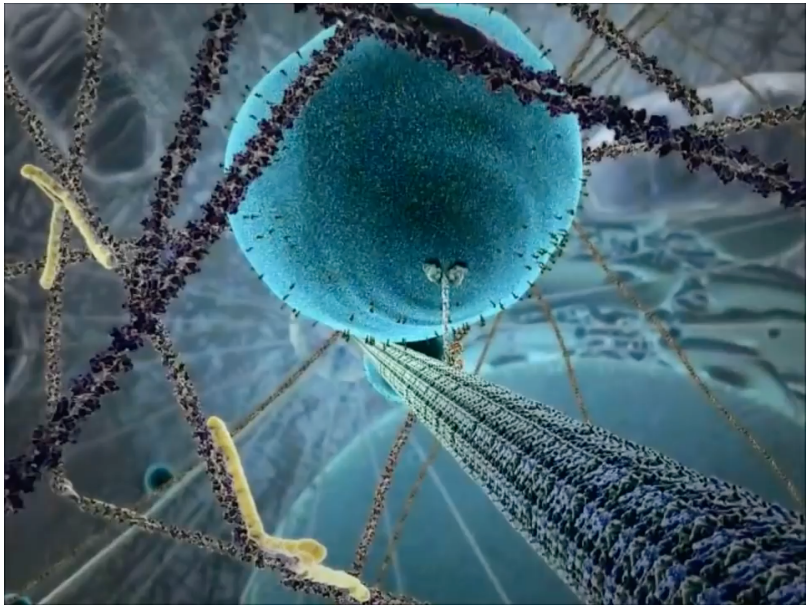
Cytoplasmic streaming in Egeria Densa(オオカナダモ).
(30x speed)

What is myosin?

Myosin is one of the motor proteins.
Chloroplasts are carried by myosins, but the mechanism is still not clear.



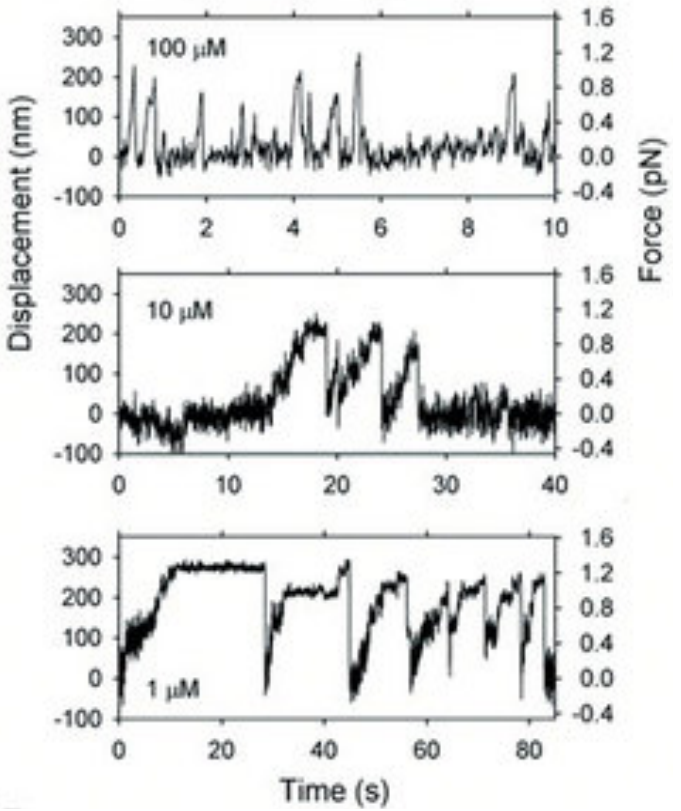
("「細胞質流動」の再現に成功！ – 人工細胞を作って、細胞の仕組みを解明する". academist Journal. https://academist-cf.com/journal/?p=4063)



(https://www.youtube.com/watch?v=y-uuk4Pr2i8)

What is myosin?

The force exerted by a myosin has been measured in vitro (outside the cell).

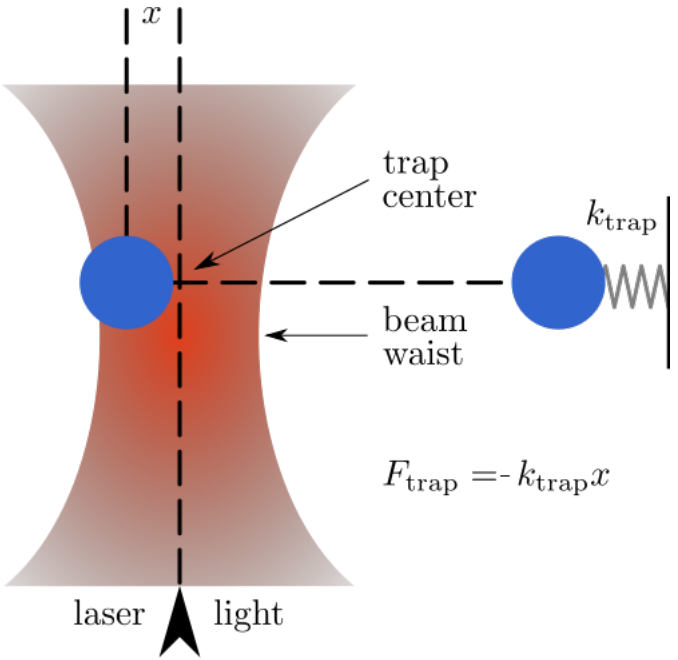


(Tominaga M, The EMBO Journal, 22, 1263-1272, 2003)

Iwaya-kun and I tried to measure the force in vivo(inside the cell).

What is Optical tweezers?

- By focusing laser, a particle can be trapped at around its focus
- Often used to measure the force a motor protein which is pulling a 1 μm polystyrene bead

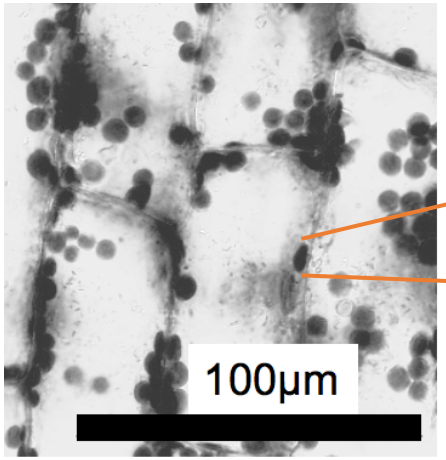


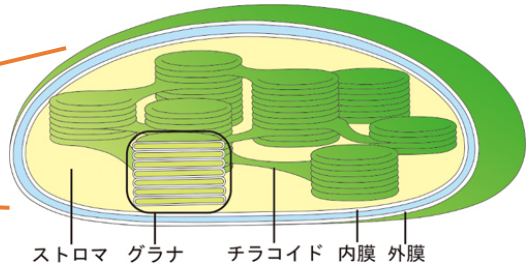
(https://en.wikipedia.org/wiki/Optical_tweezers#/media/File:Optical_trap_principle_formula_edit.svg)

Idea

It is difficult to inject beads into plant cells…

We trapped a chloroplast instead of a bead.





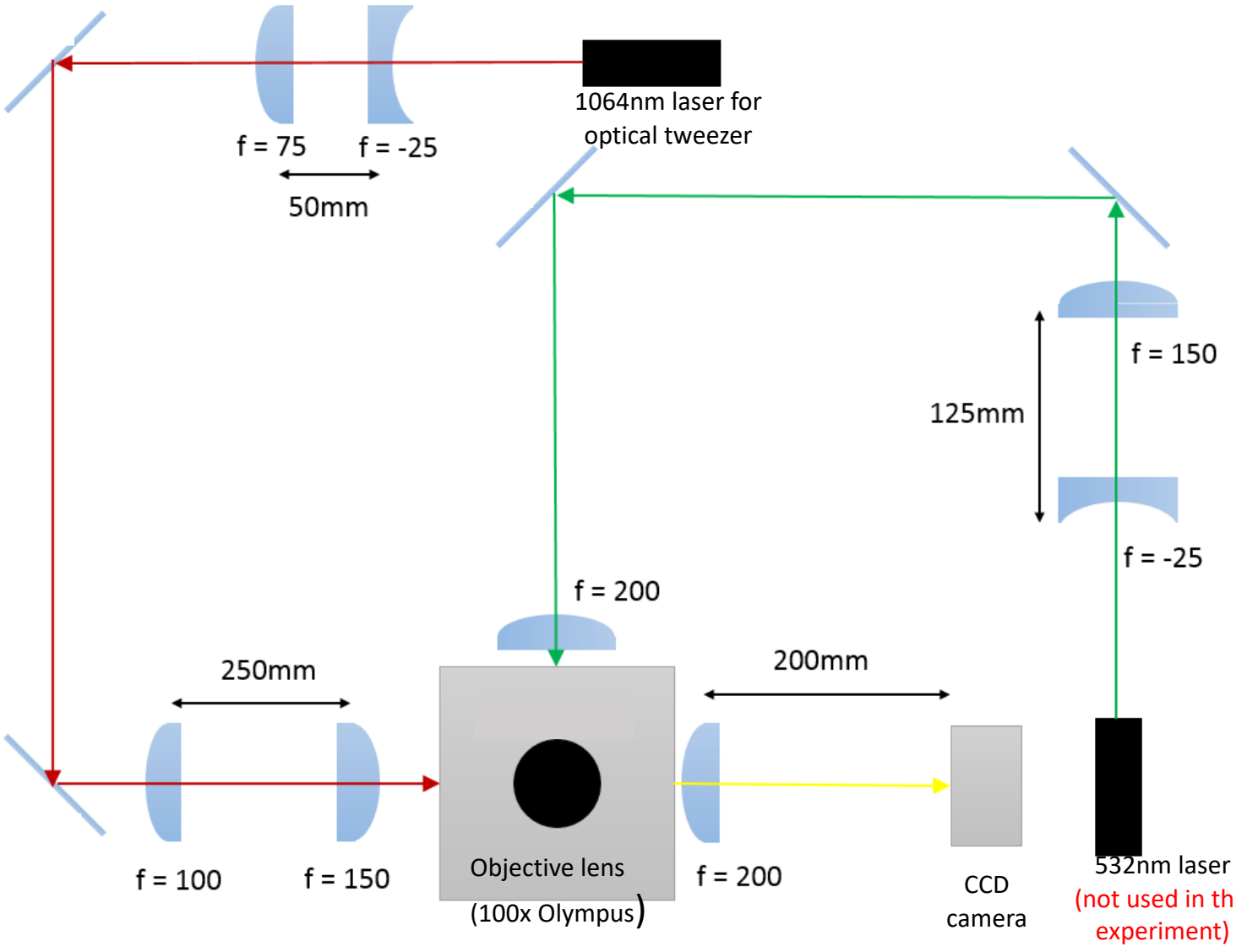
(NanotechJapan Bulletin. https://www.nanonet.go.jp/magazine/feature/excellent-result/21.html)

Outline of experiments

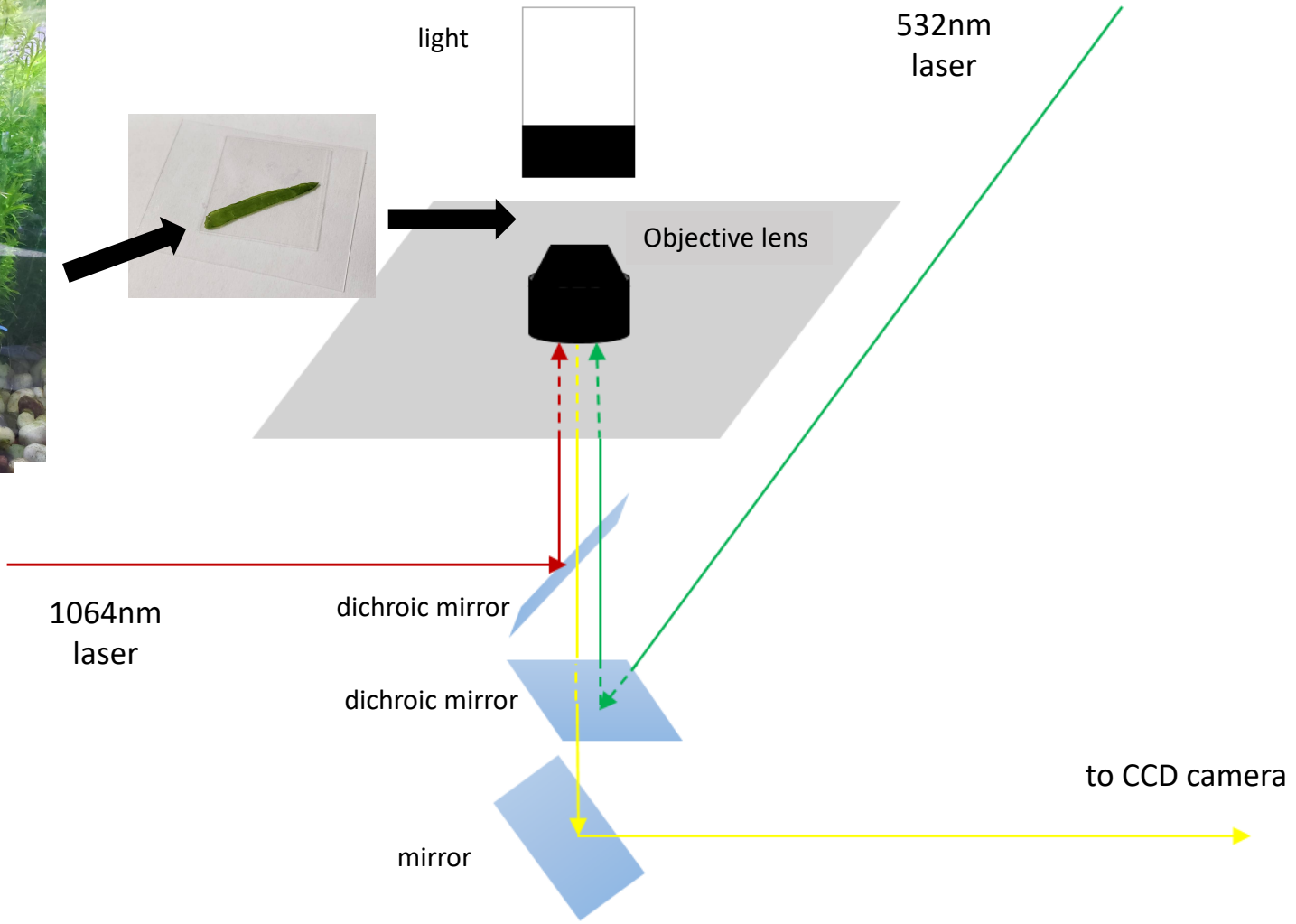
① Measuring the spring constant of optical tweezers

② Measuring the force exerted by a myosin in a cell of egeria densa(オオカナダモ)

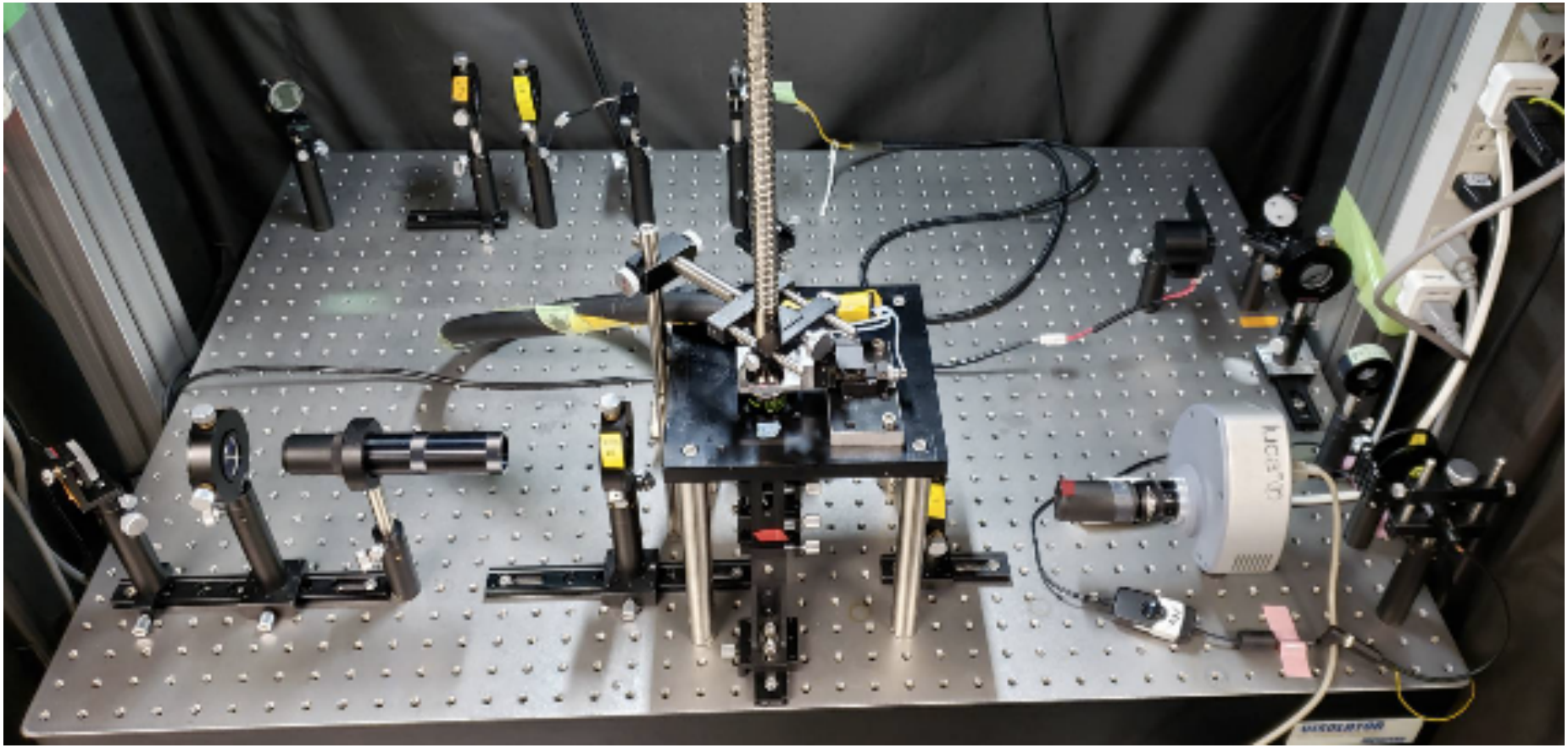
Microscope and Optical tweezers



Microscope and Optical tweezers



Microscope and Optical tweezers



① Measuring the spring constant of optical tweezers

- Outline

Trap a chloroplast which is not flowing

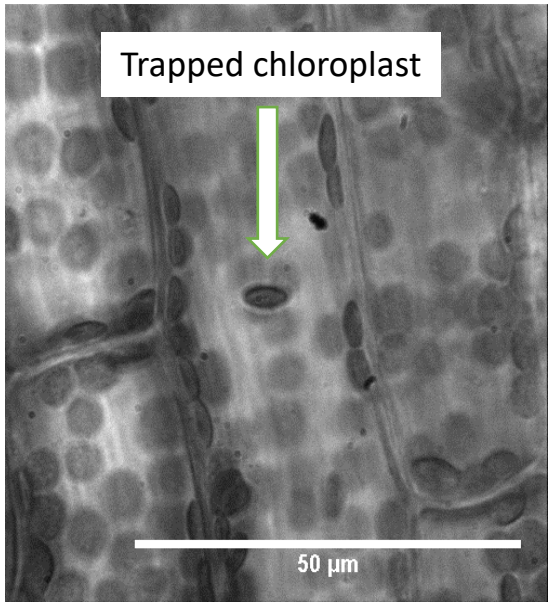
↓

Record its Brownian motion by CCD camera

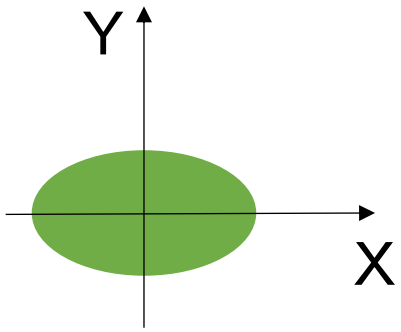
↓

Calculate the spring constant for the direction of major axis X and minor axis Y

Measure spring constant in different laser power

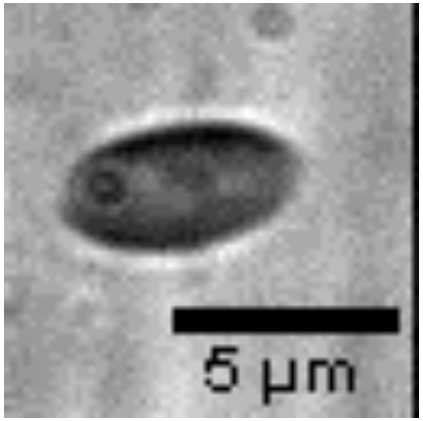


2.4x speed



① Measuring the spring constant of optical tweezers

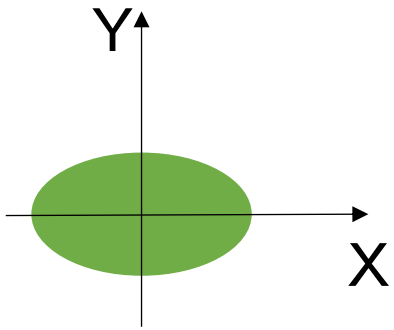
- Methods



Record Brownian motion
(frame rate: 0.038s × 100 frames)

Measure its variance σ_X^2, σ_Y^2

Calculate spring constant K_X, K_Y



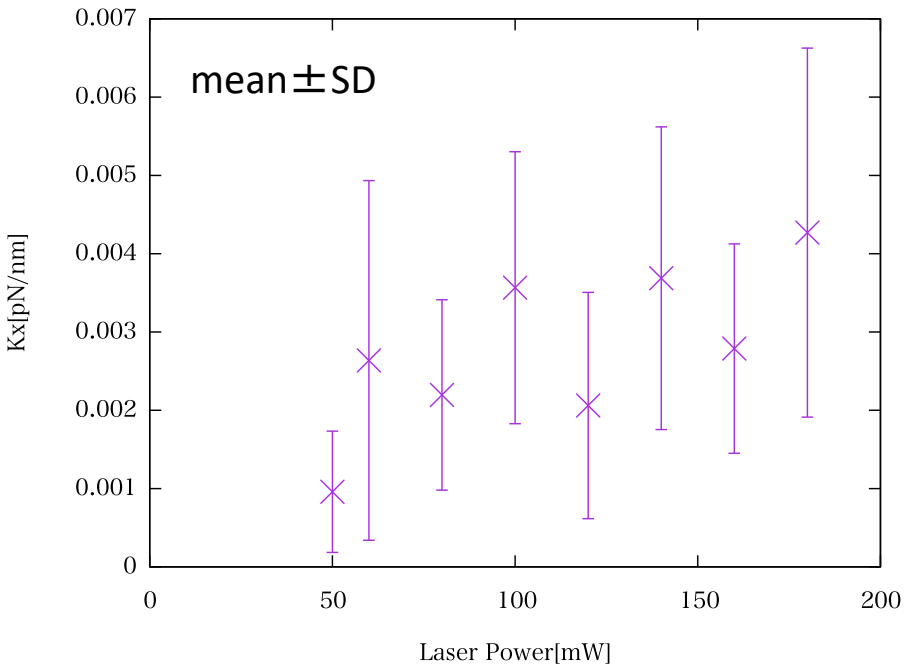
$$K_X = \frac{k_B T}{\sigma_X^2}$$

$$K_Y = \frac{k_B T}{\sigma_Y^2}$$

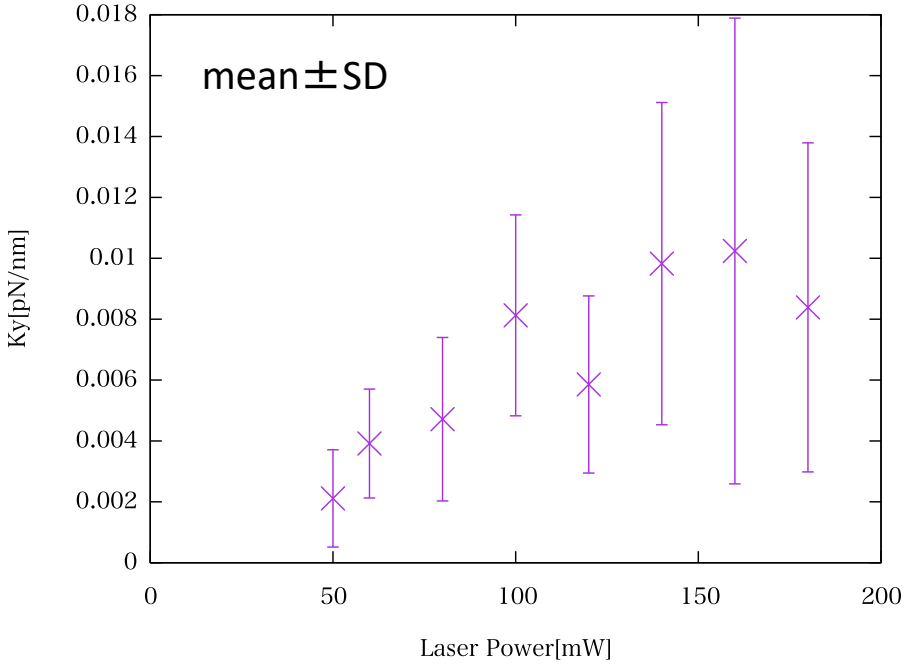
① Measuring the spring constant of optical tweezers

- Result

K_X



K_Y



① Measuring the spring constant of optical tweezers

- Power spectrum of trapped chloroplast

Langevin eq

$$m\frac{d^2x}{dt^2} = -\zeta\frac{dx}{dt} - Kx + f_R$$

$$P(f) = \frac{2k_BT\zeta}{K^2}\frac{1}{1+\left(\frac{f}{f_0}\right)^2}, \quad f_0 \equiv \frac{K}{2\pi\zeta}$$

When $f_s/2 \leq f_0$ (f_s:frame rate of camera 27Hz), aliasing error gets bigger

Not Reliable $f_s/2 \leq f_0$

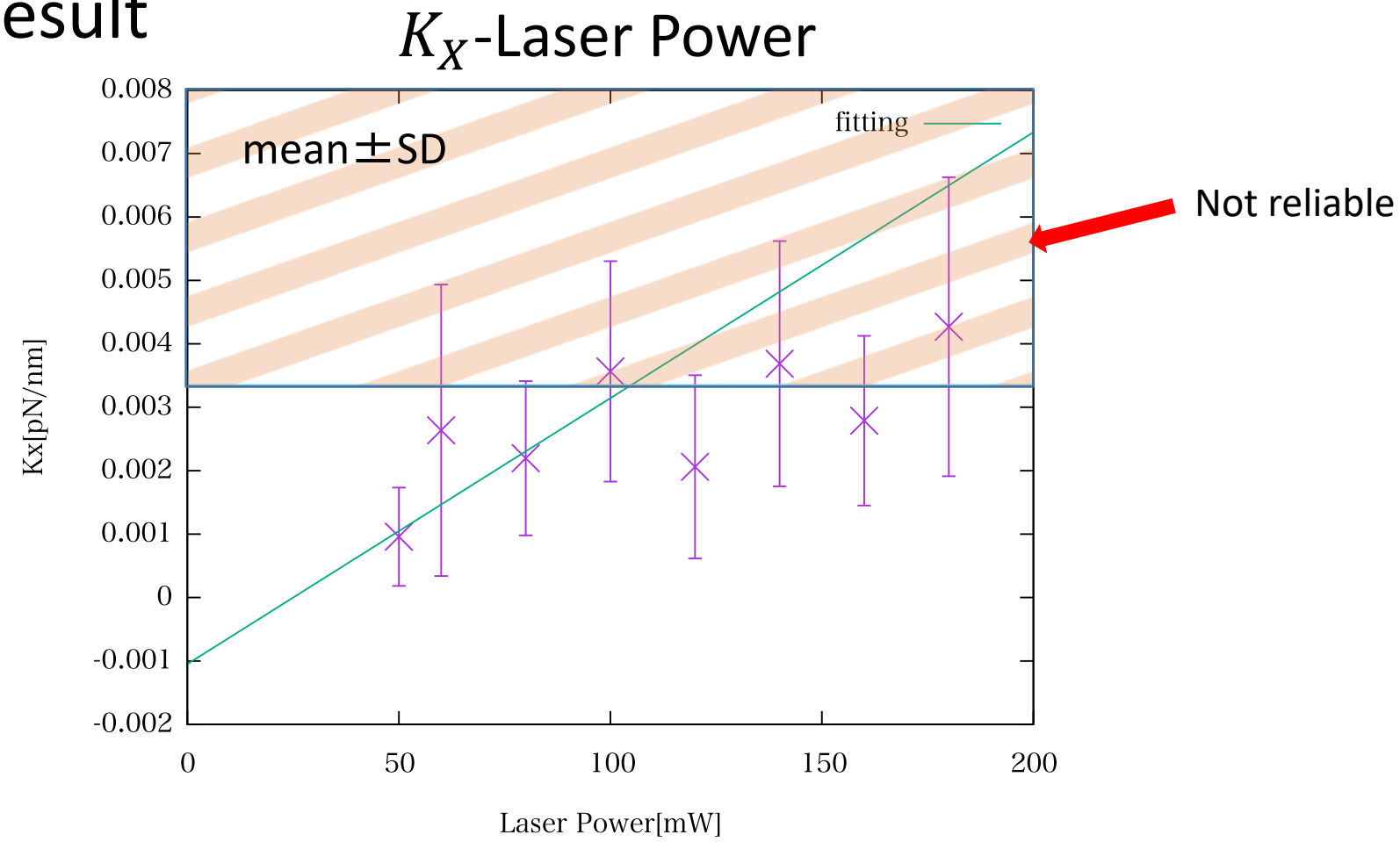
$$K \geq \begin{cases} 0.00335\ pN/nm & \text{(major axis X)} \\ 0.00383\ pN/nm & \text{(minor axis Y)} \end{cases}$$

Not Reliable

In this range of K, measured variance σ_X^2, σ_Y^2 are not reliable

① Measuring the spring constant of optical tweezers

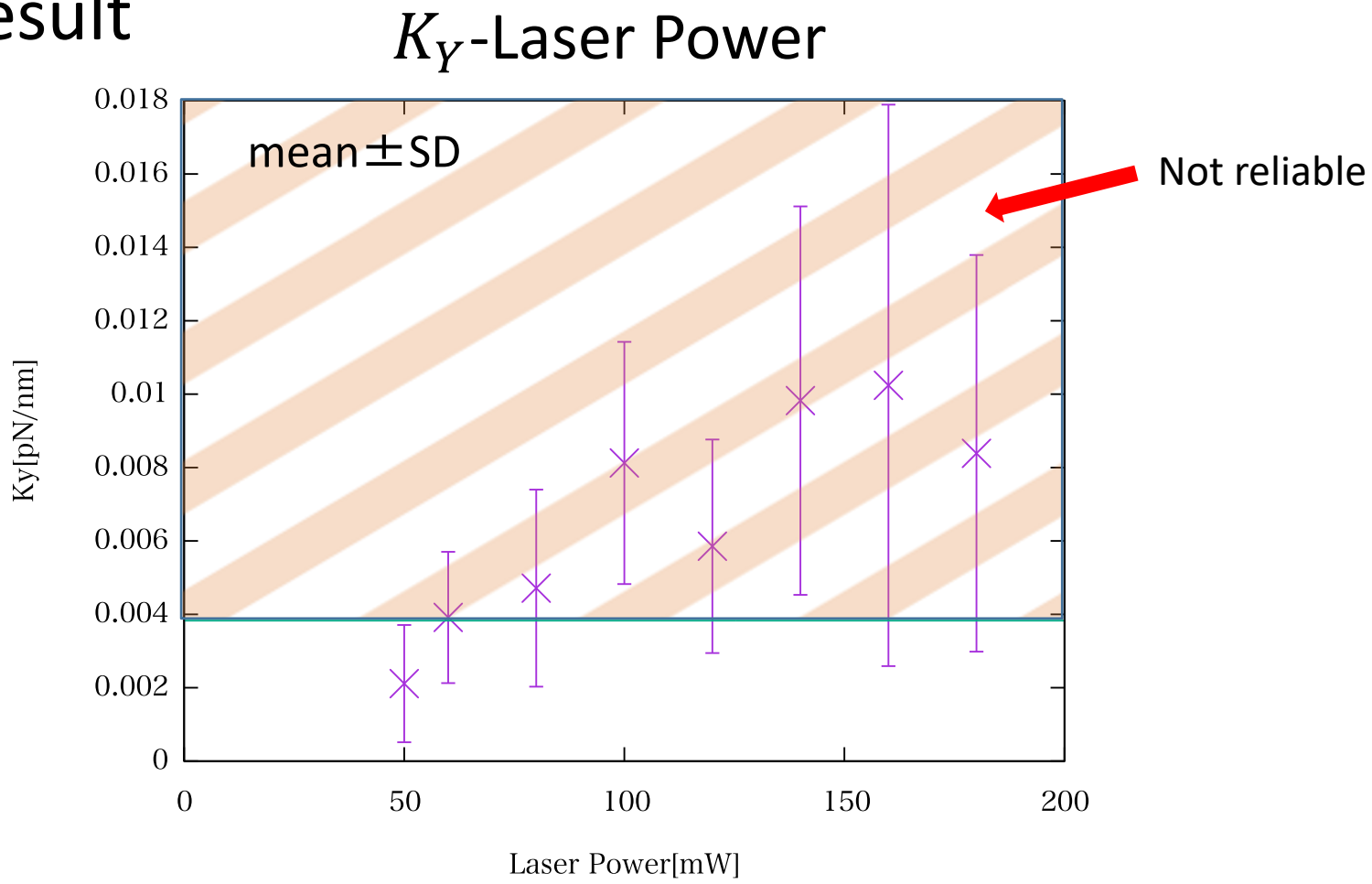
- Result



First three points are used for fitting

① Measuring the spring constant of optical tweezers

- Result



① Measuring the spring constant of optical tweezers

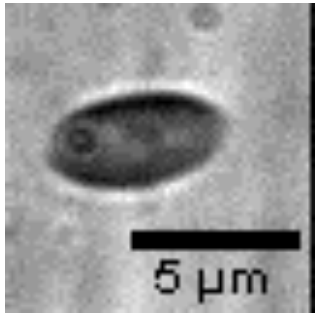
- Result

$$K_X\ [\mathrm{pN/nm}] = a \times P\ [\mathrm{mW}] + b$$

$$a = (4 \pm 2) \times 10^{-5}\ \mathrm{pN/nm/mW}$$

$$b = -(1 \pm 2) \times 10^{-3}\ \mathrm{pN/nm}$$

- What caused this poor accuracy?
  - Lack of data points
  - Aliasing error due to the low frame rate?
  - Rotation while recording?

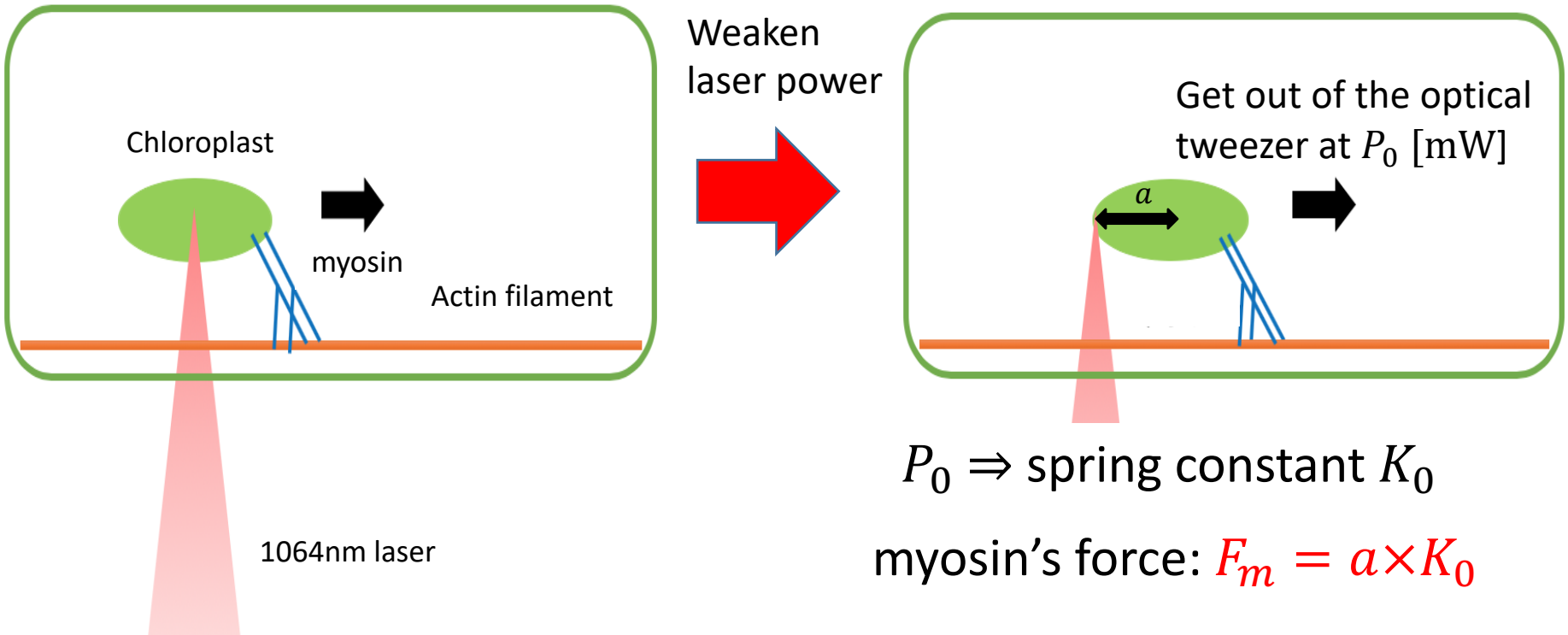


②Measuring the force exerted by a myosin

- Idea

  The force of optical tweezers is almost linear to the edge of spherical particle

  ➡ Assume this is true of chloroplast

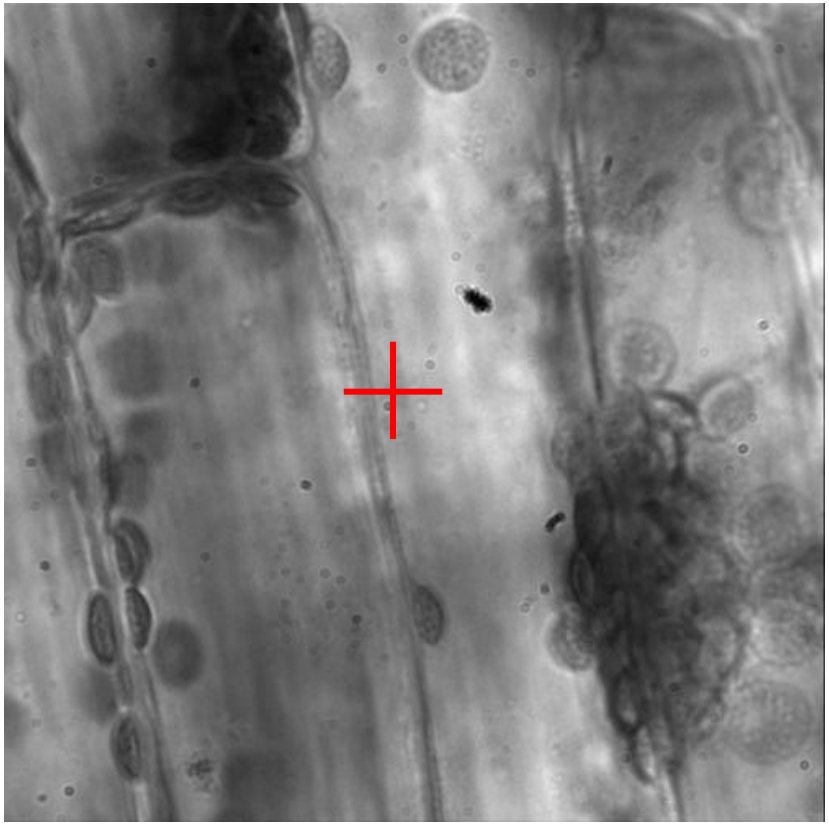


$P_0 \Rightarrow$ spring constant K_0

myosin's force: $F_m = a \times K_0$

②Measuring the force exerted by a myosin

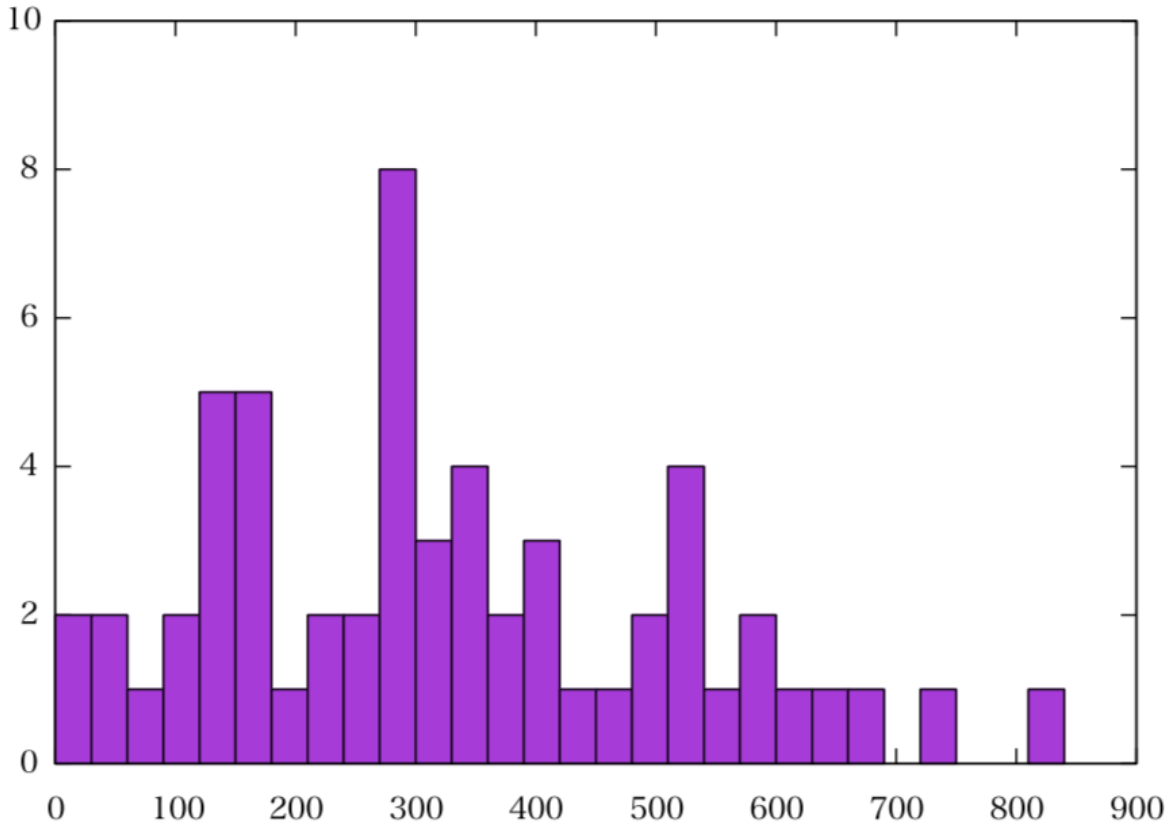
- Methods



3x speed

②Measuring the force exerted by a myosin

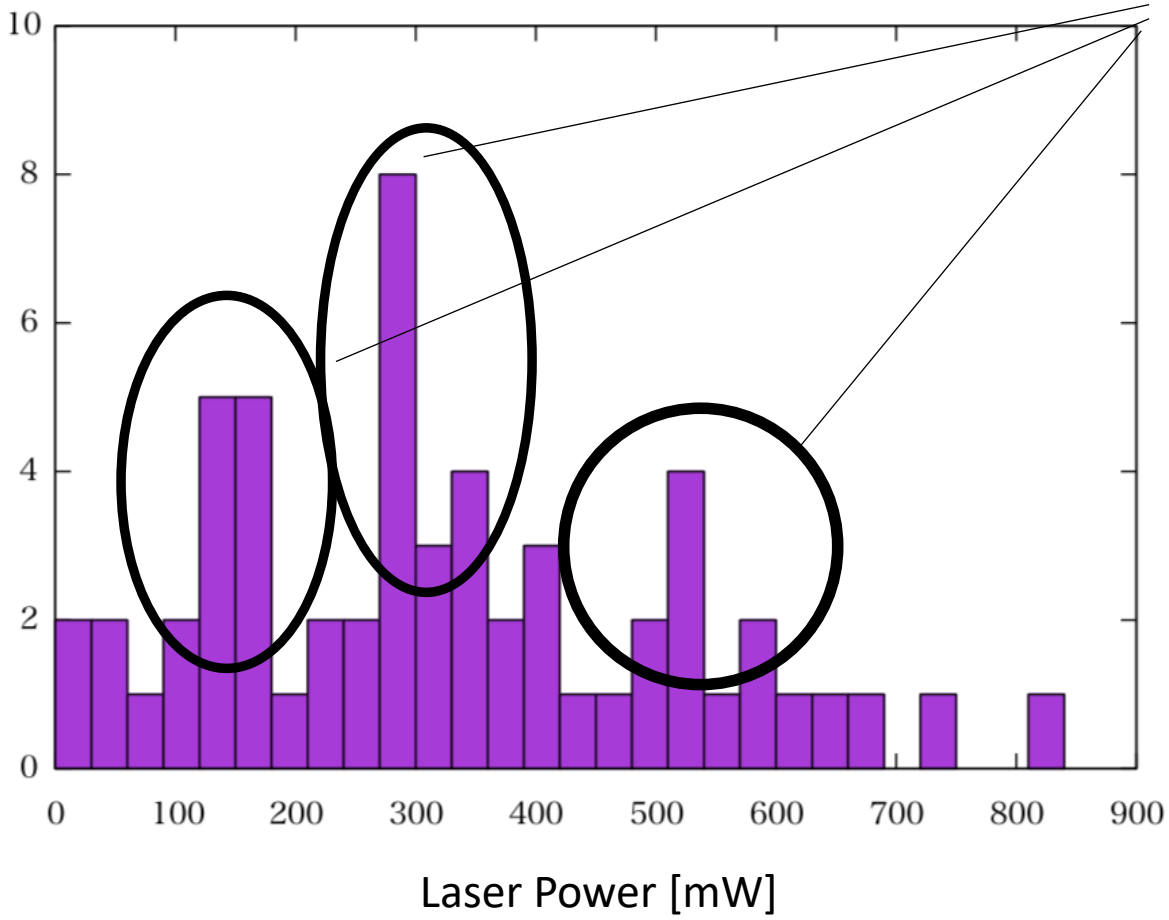
- Result



No. of data: 58
Bin width: 30mW

②Measuring the force exerted by a myosin

- Discussion

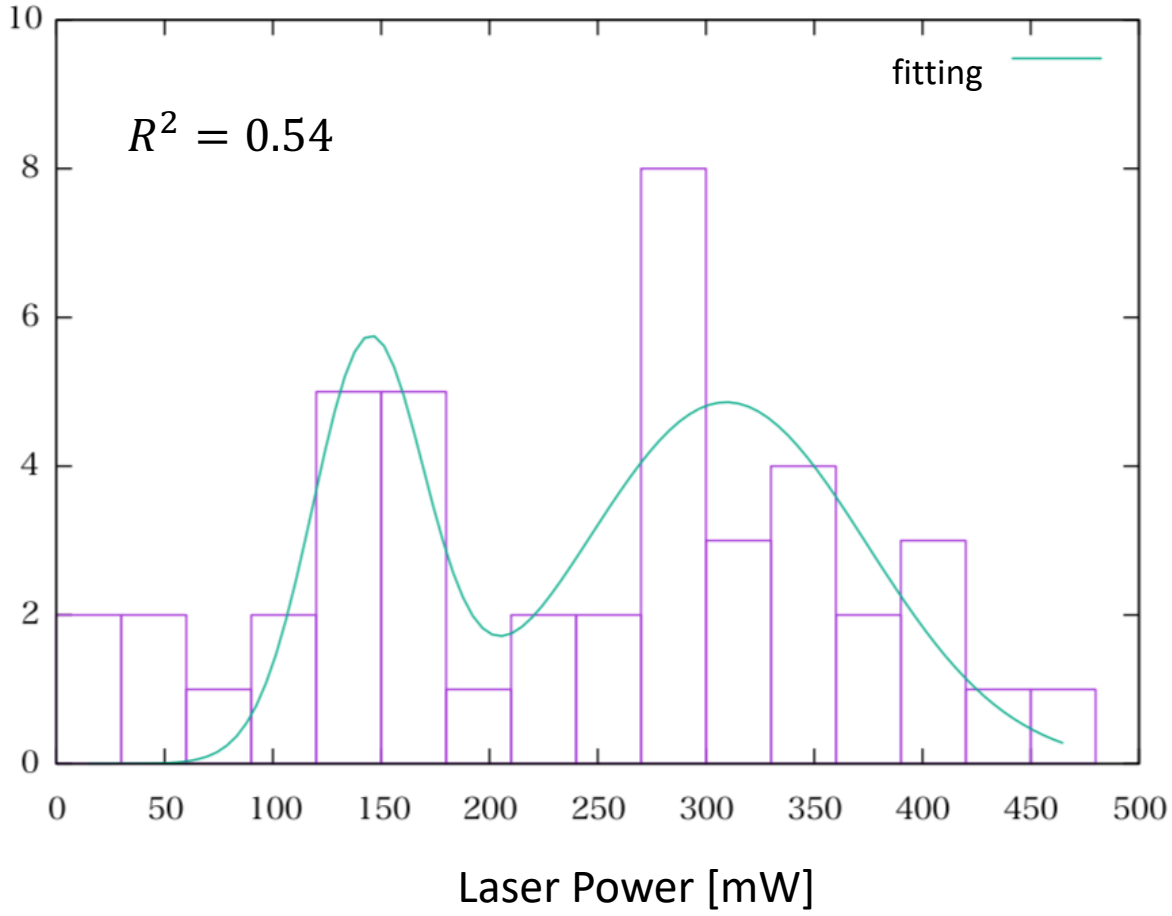


There seems to exist peaks

$F_m \propto$ No. of myosins?

②Measuring the force exerted by a myosin

- Discussion



Gaussian fitting to the first two peaks

$$P_1 = 144 \pm 10\ mW$$

$$P_2 = 309 \pm 18\ mW$$

Assume

P_1 : a single myosin

P_2 : 2 myosins

②Measuring the force exerted by a myosin

- Discussion

$$P_1 = 144 \pm 10\ mW$$

Result of experiment ①

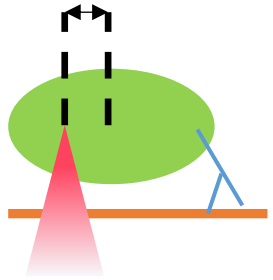
A single myosin : $F_m = 14 \pm 12\ pN$

(Myosin in vitro: 1.2 pN)

- To improve accuracy

Need more precise K_X −Laser power relation

Measure the force of myosin from displacement



Self introduction

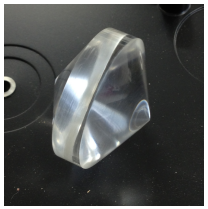
My name is
Hiroki Fujimoto / 藤本 拓希

Self introduction

- My life so far

1997.7 :

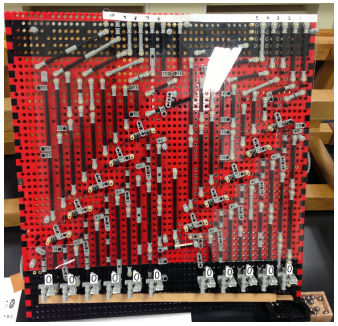
born in Toyama, grew up in Fukuoka

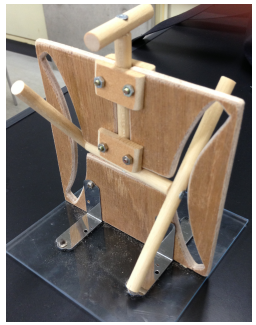


2013.4～2016.3 :

Shuyukan(修猷館) high school

Belonged to physics club, math club and swimming club

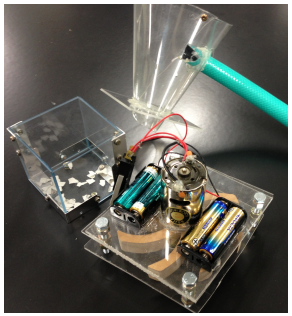




2016.4～2020.3 :

Univ. of Tokyo Natural Science Ⅰ

⇒Dept. of Physics



2020.4 ～ :

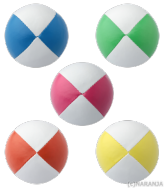
Graduate school, Ando lab

Boy in a funny tracksuit (me)

Self introduction

- My hobby : Juggling

I play diabolo and balls



@ Newton Festival 2018
photo by Oshima-san

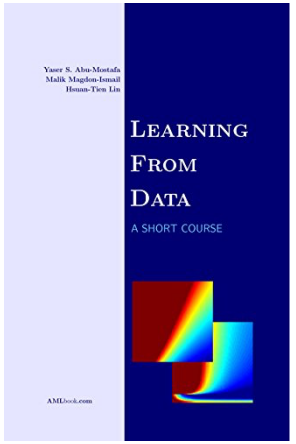
@ Komaba Festival 2017

Part 2

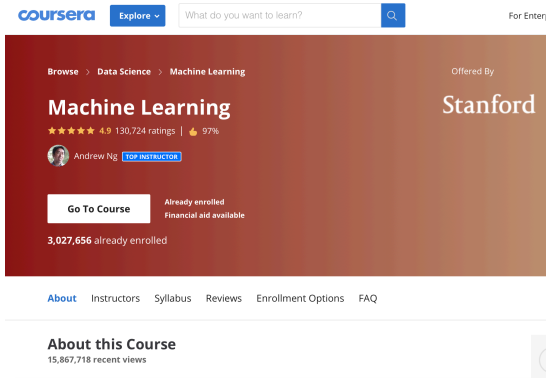
Analyzing stellar spectra with machine learning

What I did in the seminar

- Learned the theoretical part of machine learning with “Learning from Data”



- Learned the practical part of machine learning with Coursera online course “Machine Learning”



- In the end of the seminar, we had a competition of analyzing stellar spectra with machine learning

Contents of Part 2

- What is machine learning(ML)?
- What is Neural Network?
- Analyzing stellar spectra with ML

What is machine learning?

- Supervised learning

Motivation

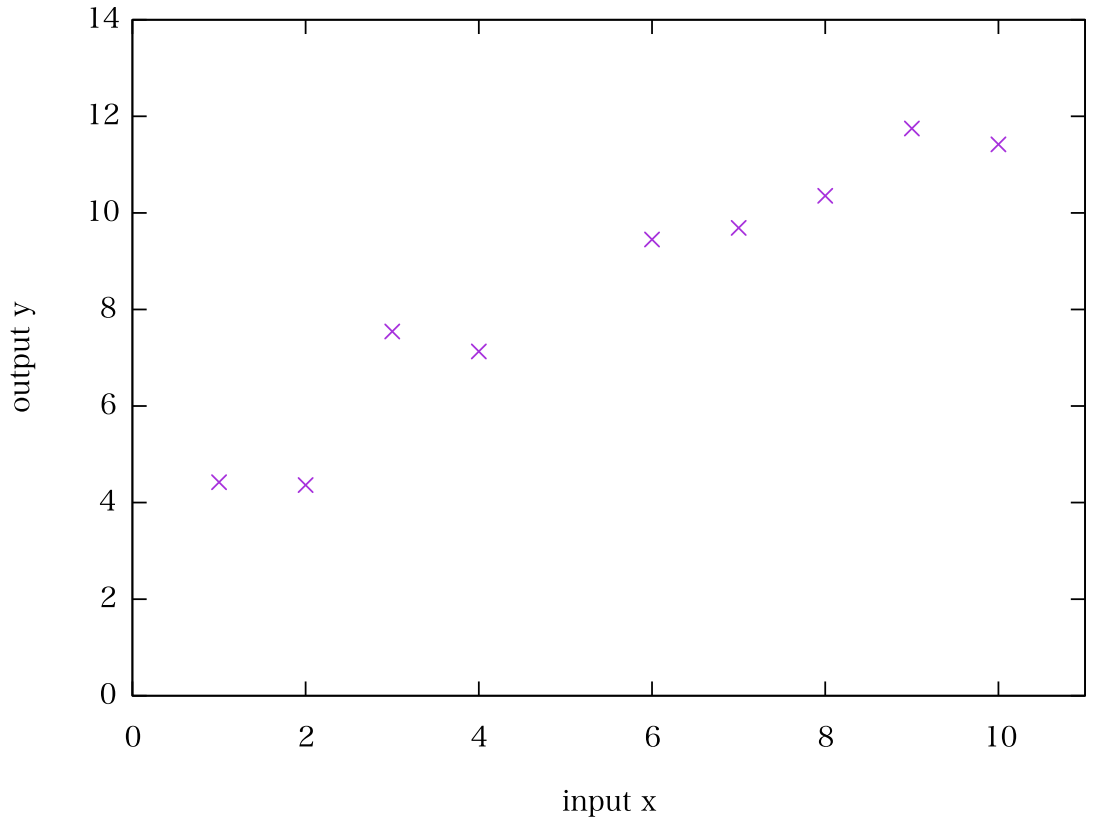
Many data: $\{(input: x_i, output: y_i)\}_{i=1\sim N}$

Predict y for unknown input x

What is machine learning?

- Supervised learning

What is y for x=5?



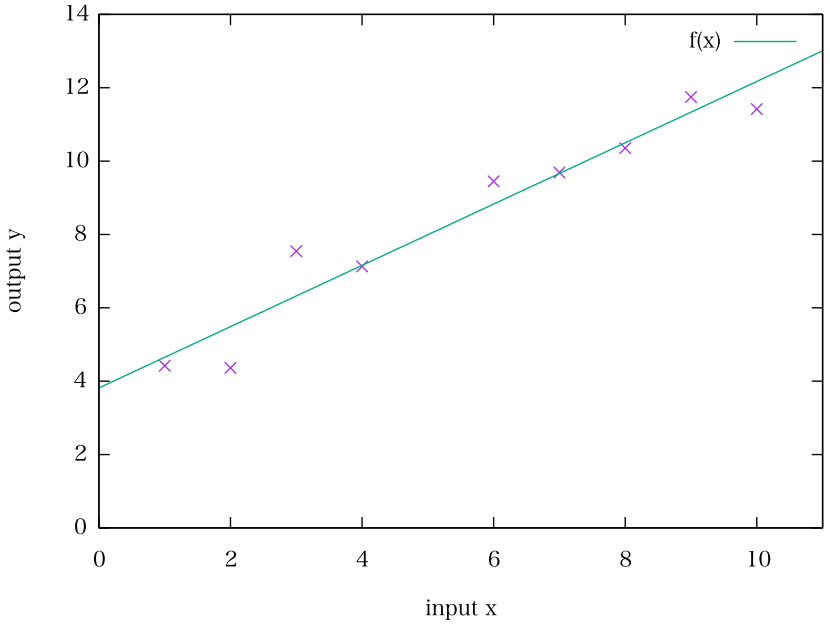
What is machine learning?

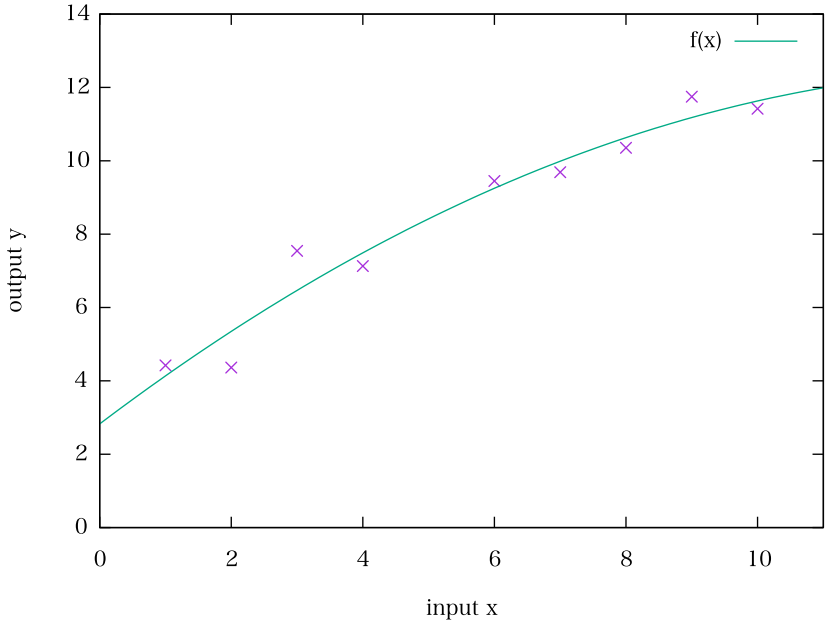
- Supervised learning

"Model"

$h_\theta(x) = \theta_0 + \theta_1 x$

$h_\theta(x) = \theta_0 + \theta_1 x + \theta_2 x^2$





What is machine learning?

- How to train a model $h_\theta(x)$

Many data: $\{(input: x_i, output: y_i)\}_{i=1\sim N}$

Cost Function: $J(\theta) = \frac{1}{N}\sum_{i=1}^{N}(h_\theta(x_i) - y_i)^2$

Minimize this ($J(\theta_{min})$: smallest)

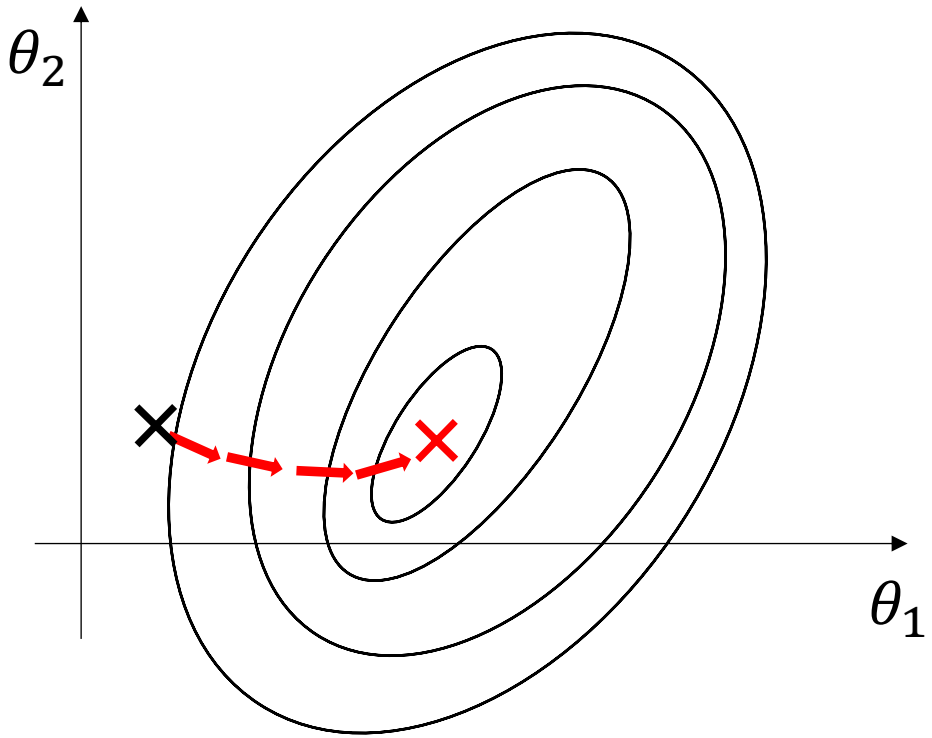
Trained model : $h_{\theta_{min}}(x)$

What is machine learning?

- Gradient Descent

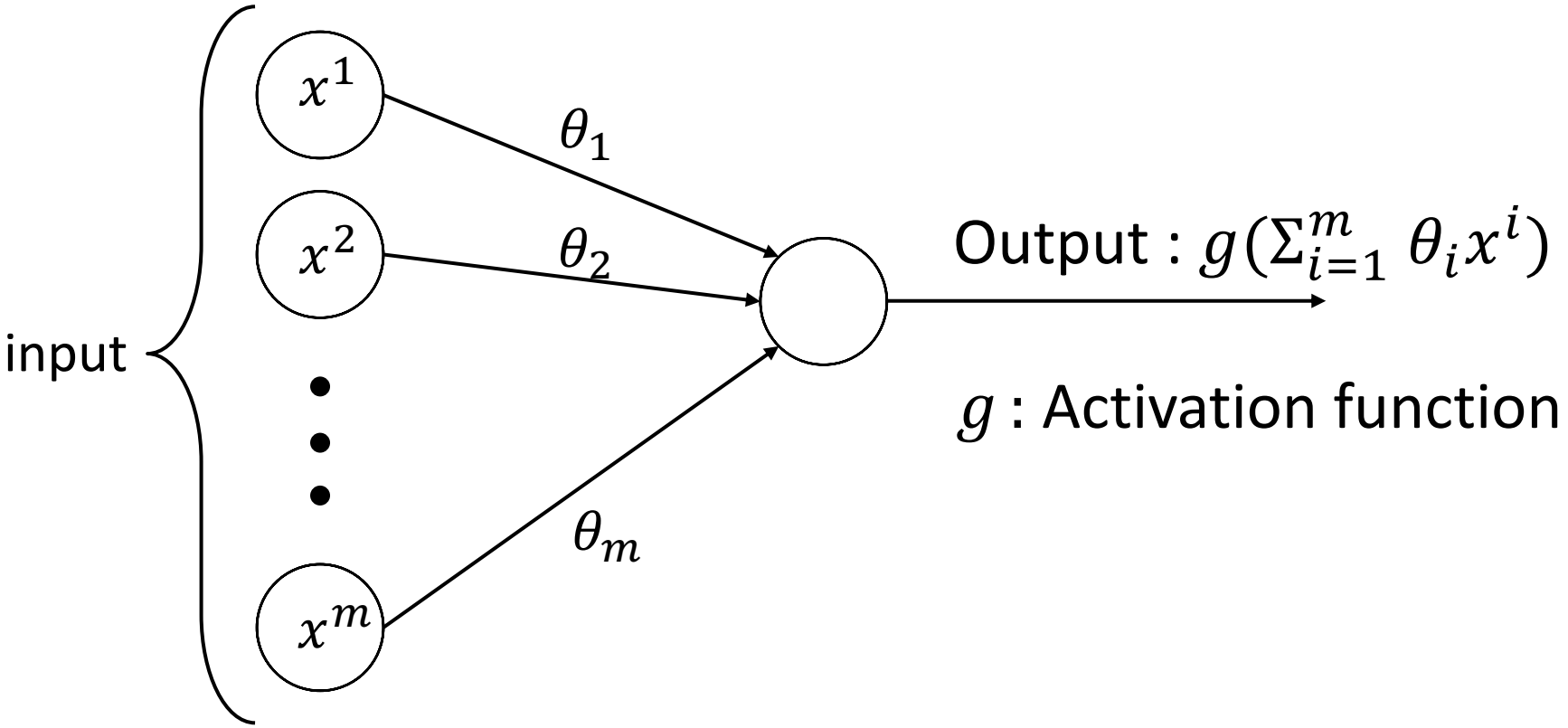
Repeat $\theta \leftarrow \theta - \alpha \nabla_\theta J(\theta)$

➡ Approach minimum point



What is Neural Network?

- Neuron model



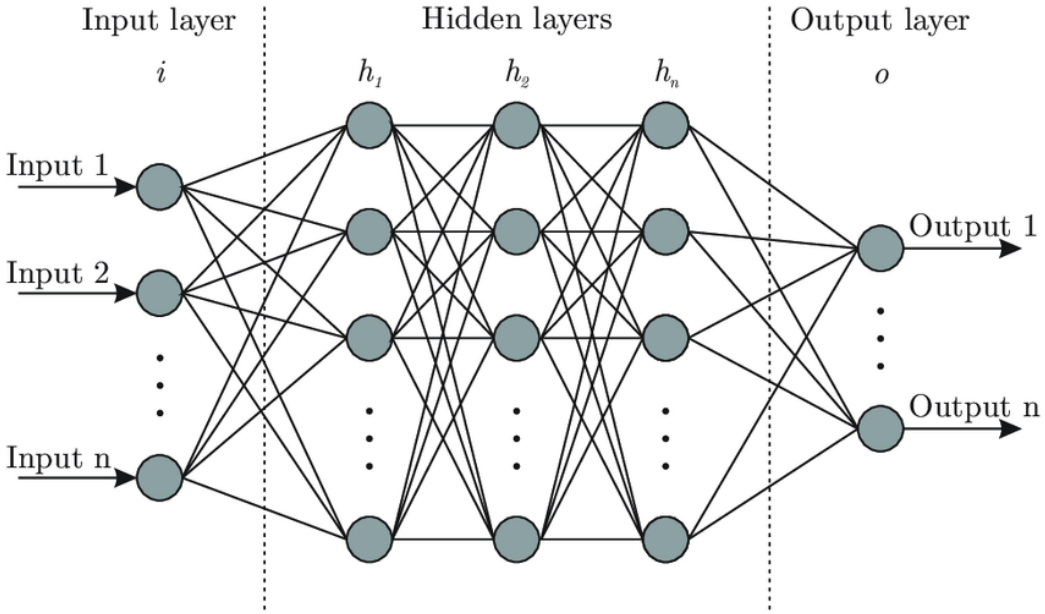
m : the dimension of input x (not No. of input data)

What is Neural Network?

- Neural Network

  Combination of neuron models

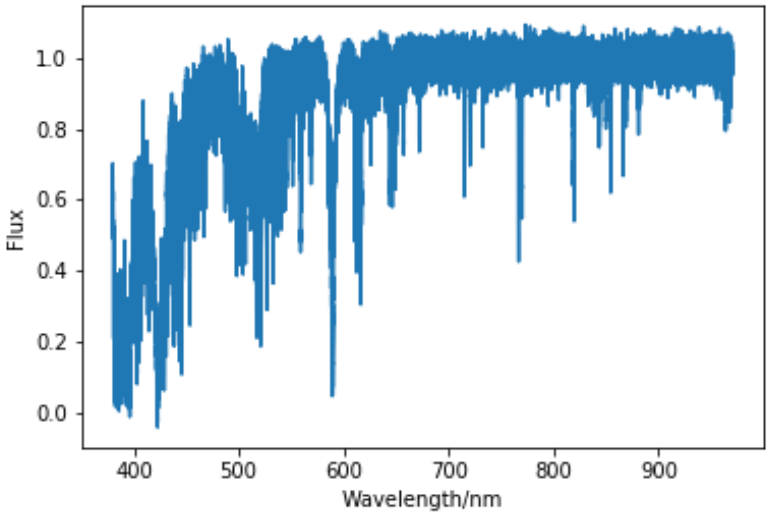
  Input and output can be vectors



(https://www.researchgate.net/publication/321259051_Prediction_of_wind_pressure_coefficients_on_building_surfaces_using_Artificial_Neural_Networks)

Analyzing stellar spectra with ML

- How to apply ML to analyzing stellar spectra



T_{eff} : effective temperature

$\log g$: surface gravity

$[M/H]$: stellar metallicity

$[\alpha/Fe]$: alpha-element

Predict with ML

Analyzing stellar spectra with ML

- Training data set and model

  6256 data of (spectrum; T_{eff} , $\log g$, $[M/H]$, $[\alpha/Fe]$)
  are given for training

  normalized to have mean value 0 and standard deviation 1

  I chose Neural Network for the model

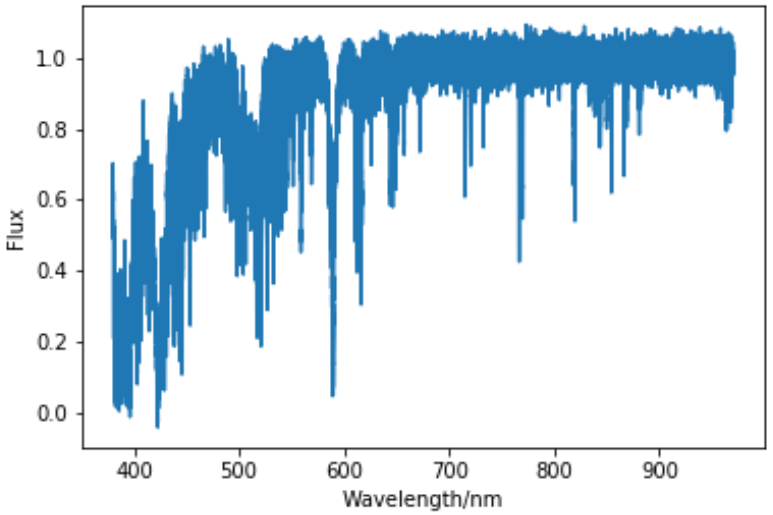
  I used python and Keras(library for Neural Network)

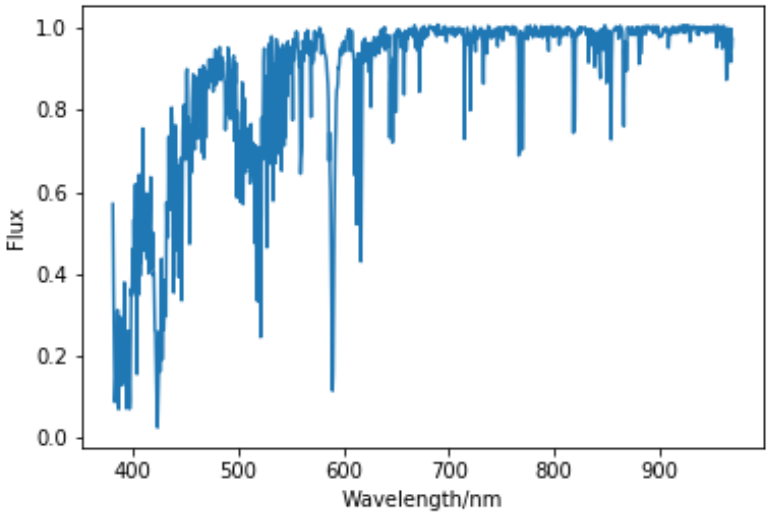
  In the competition, the performance of our models were checked with test data(not used for training)

Analyzing stellar spectra with ML

- Idea

  Take the average and decrease the resolution





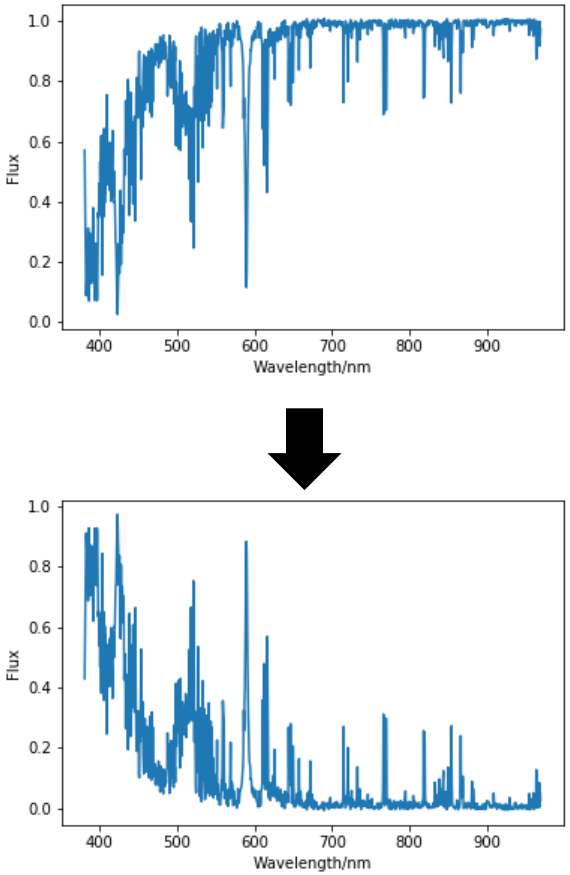
Resolution(No. of inputs) = 58998

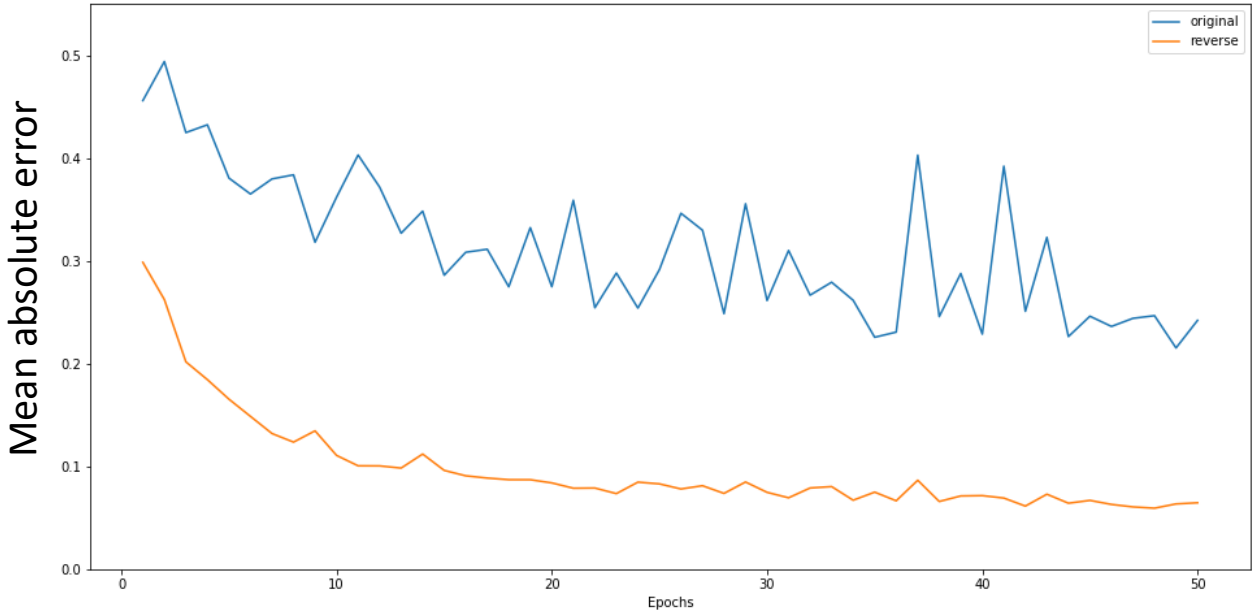
Resolution(No. of inputs) = 1179

Analyzing stellar spectra with ML

- Idea

  Reverse spectra

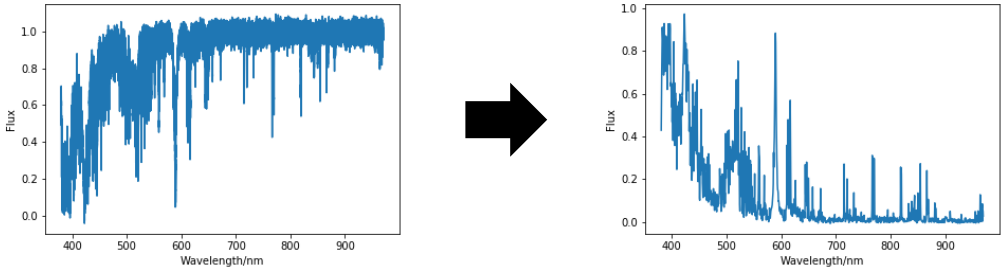




Mean absolute error for validation data(not used for training) decreased to 1/4 !

Analyzing stellar spectra with ML

- Best tuned model



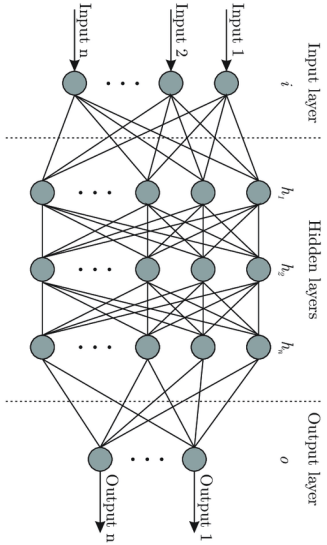
Required time for training : 25s

Input (normalized,reduced and reversed spectra) : 1179 units

Hidden layer 1 : 256 units, Activation: ReLU

Hidden layer 2 : 256 units, Activation: ReLU

Output layer : 4 units



(https://www.researchgate.net/publication/321259051_Prediction_of_wind_pressure_coefficients_on_building_surfaces_using_Artificial_Neural_Networks)

Analyzing stellar spectra with ML

- Performance for test data

Test my model with 1103 Test data

⬇

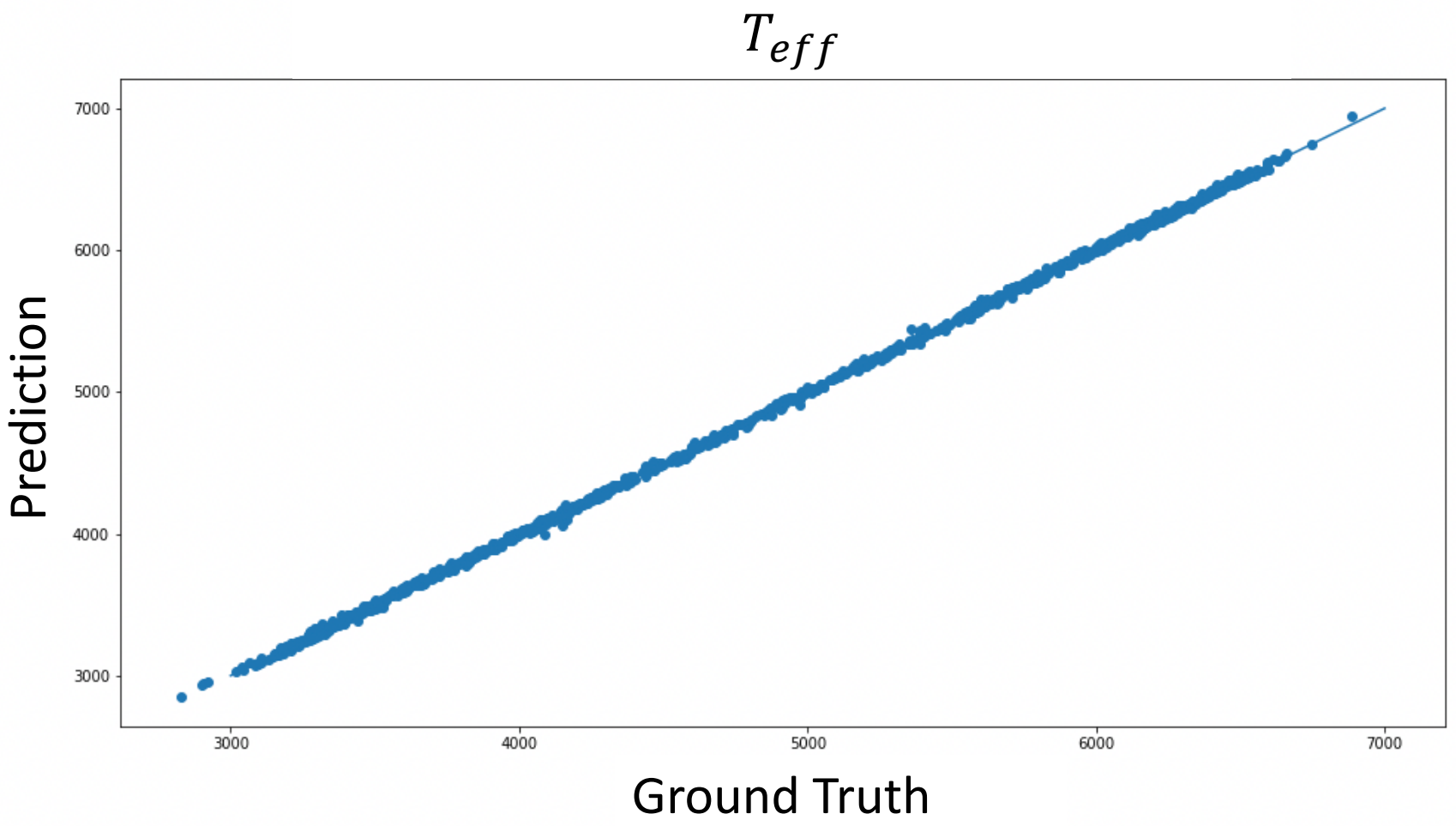
Mean absolute error : 0.058

Mean square error(cost function) : 0.0071

Notice : T_{eff} , $\log g$, $[M/H]$, $[\alpha/Fe]$ are normalized here
(mean=0, standard deviation=1)

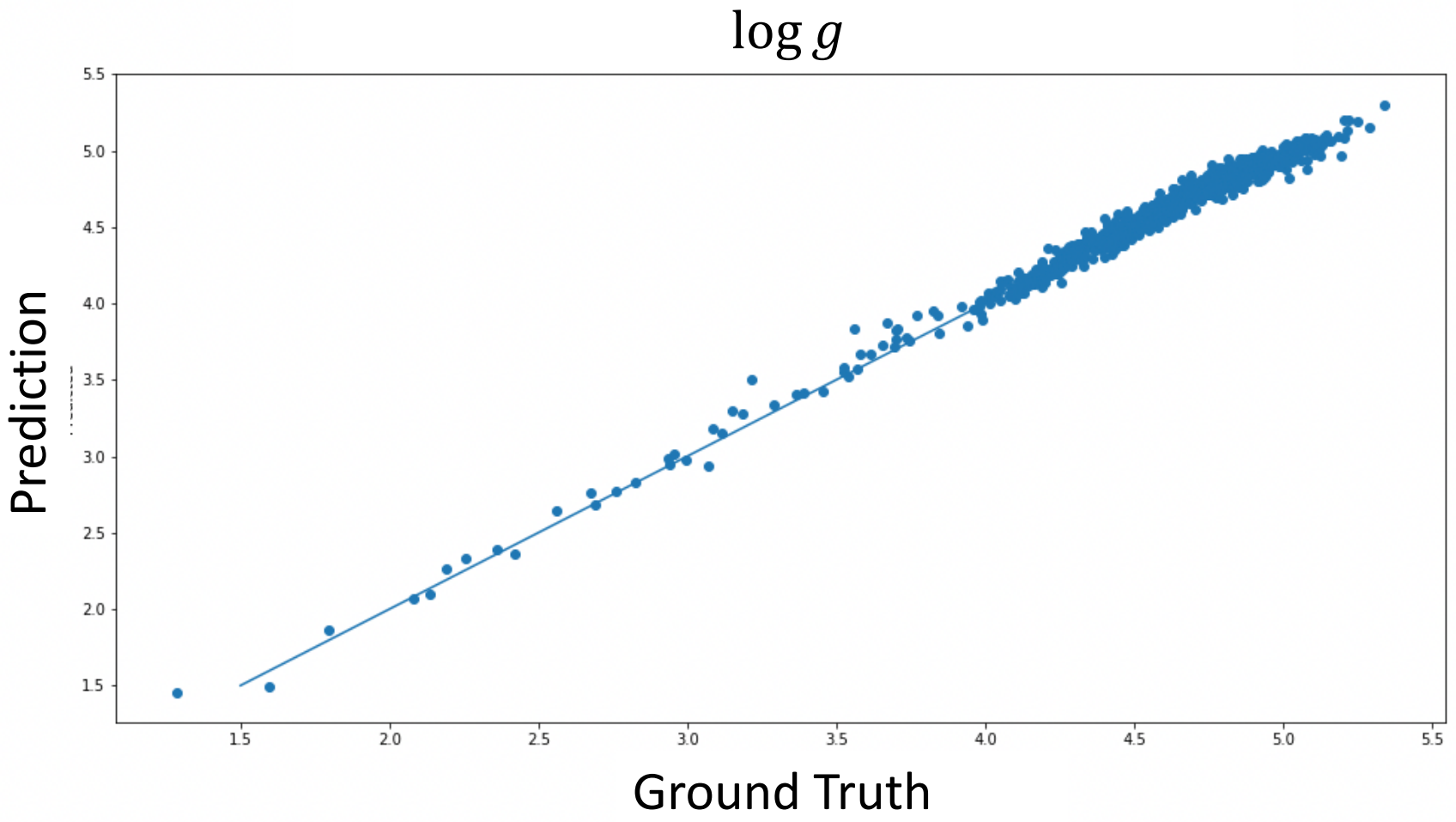
Analyzing stellar spectra with ML

- Performance for test data



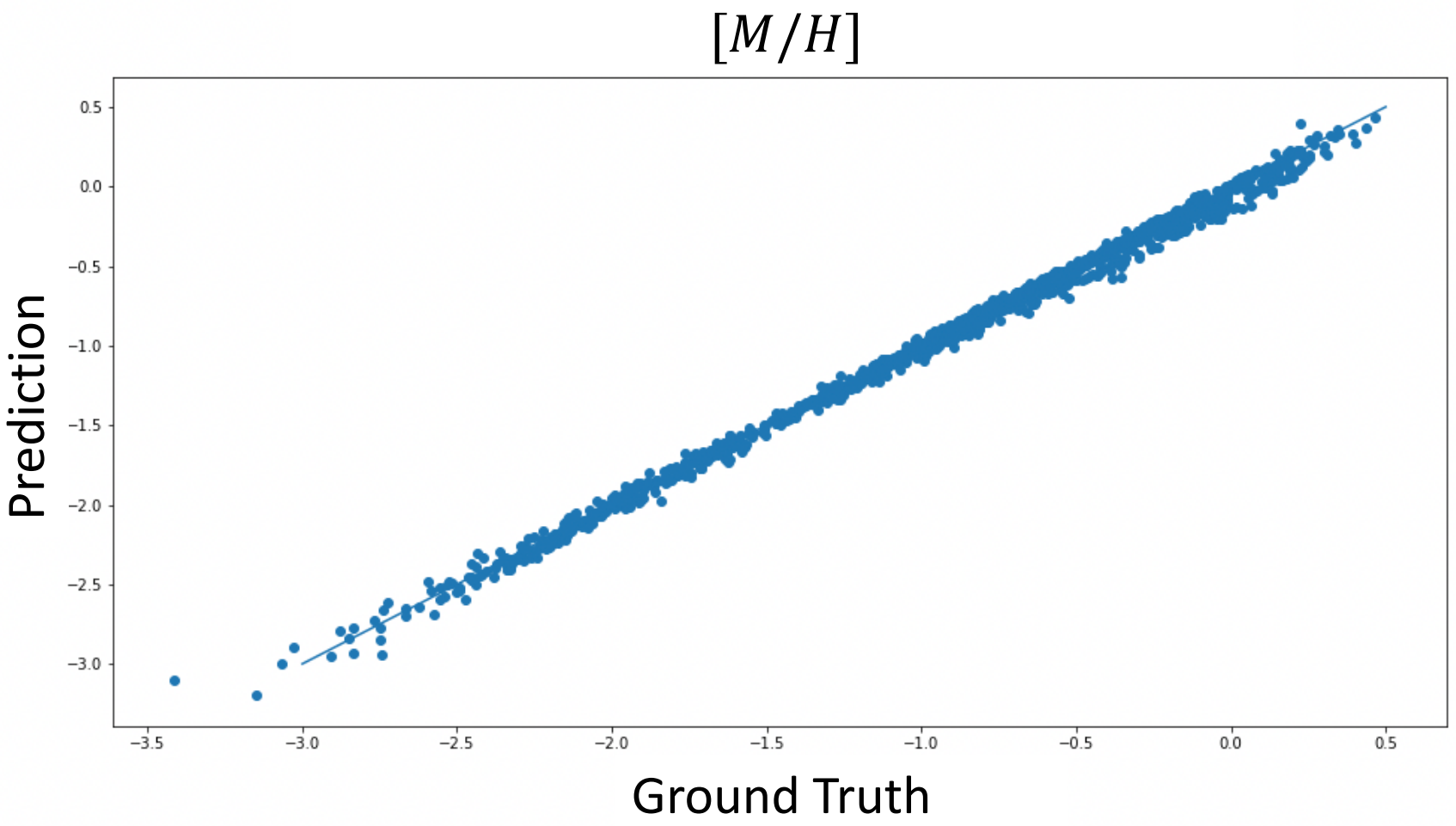
Analyzing stellar spectra with ML

- Performance for test data



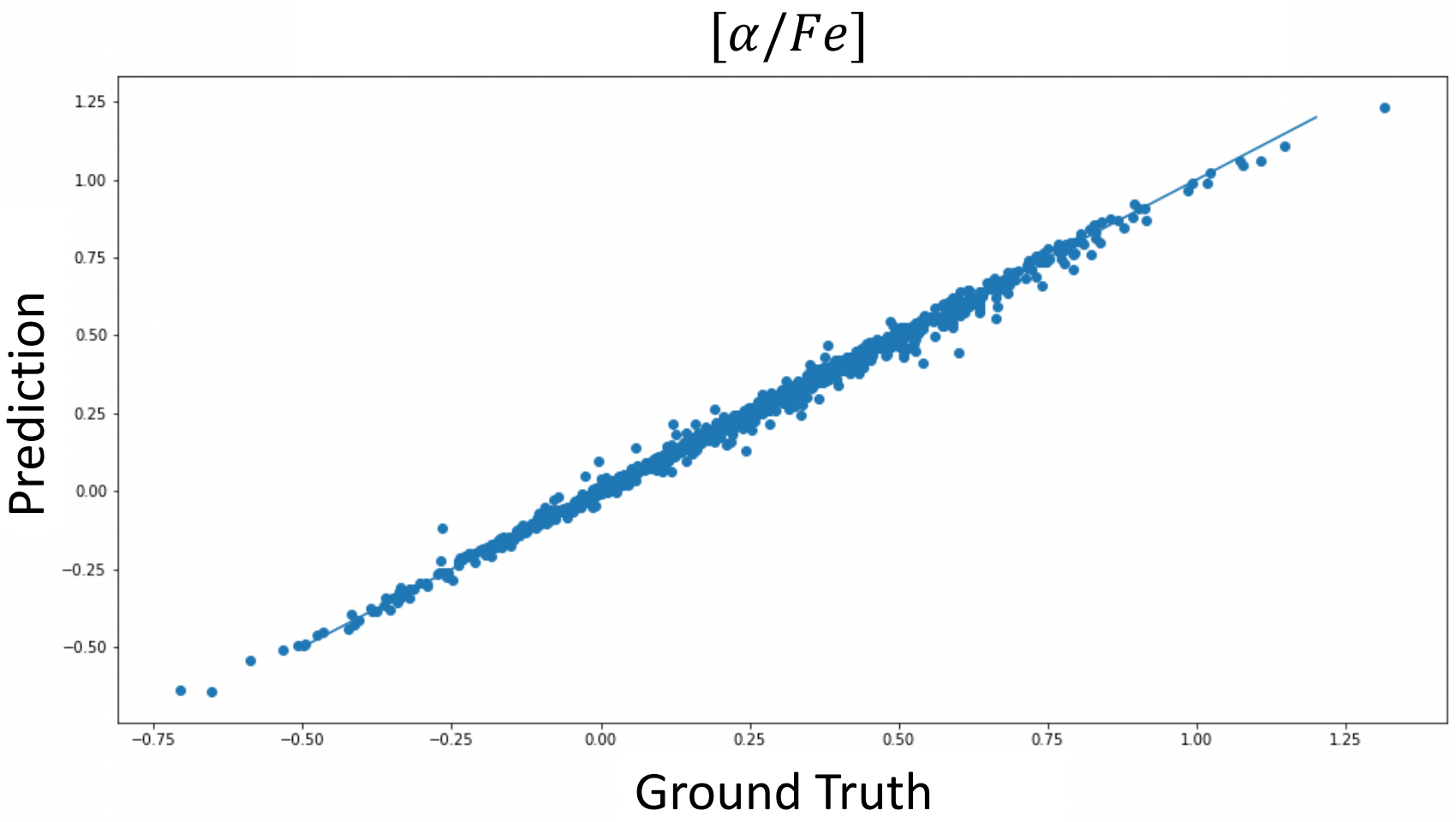
Analyzing stellar spectra with ML

- Performance for test data



Analyzing stellar spectra with ML

- Performance for test data



Thank you for listening