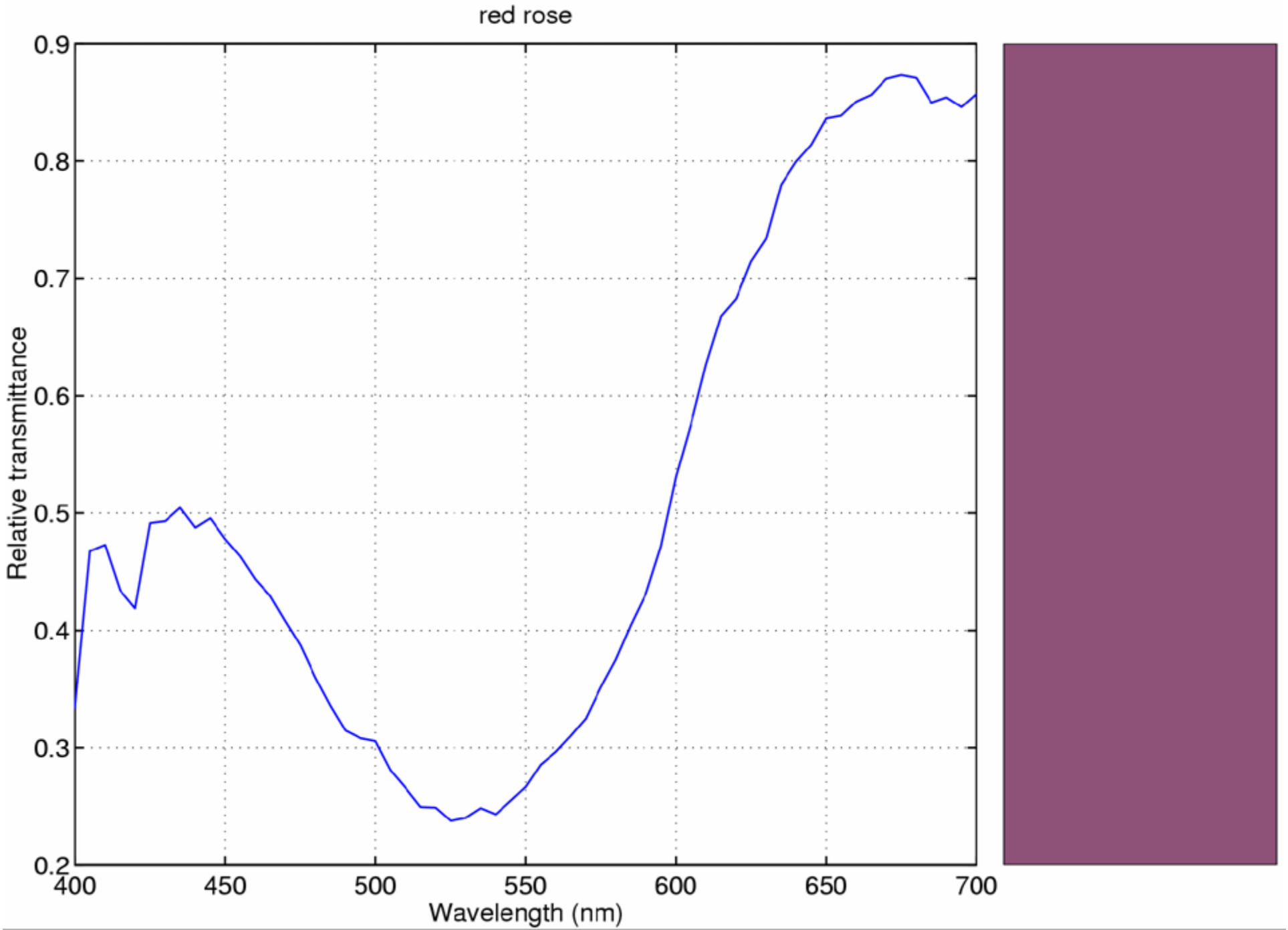
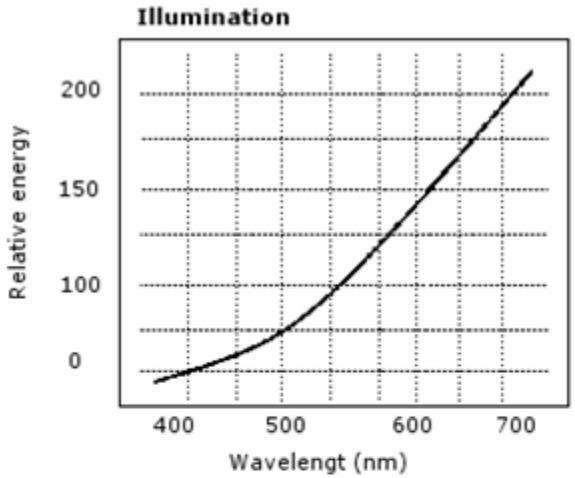
Digital Color

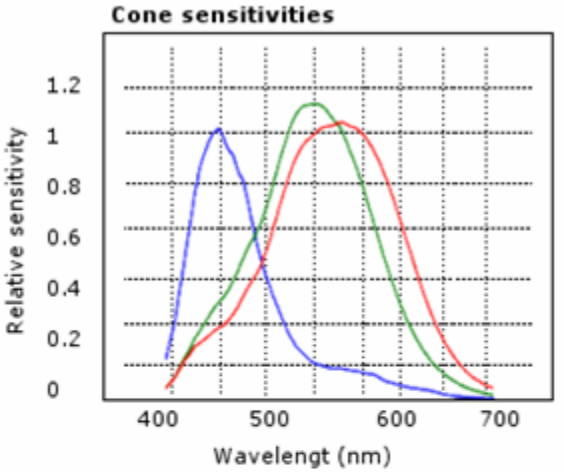
Lecture 8

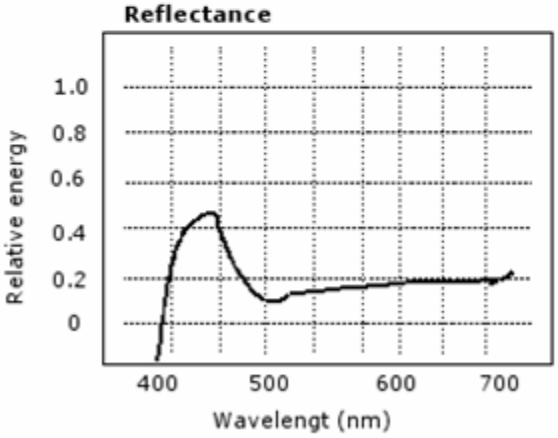
Biomolecules for color image processing

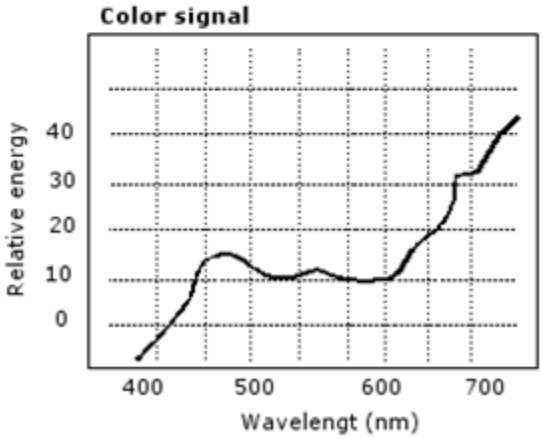

red rose
Relative transmittance
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
400
450
500
550
600
650
700
Wavelength (nm)

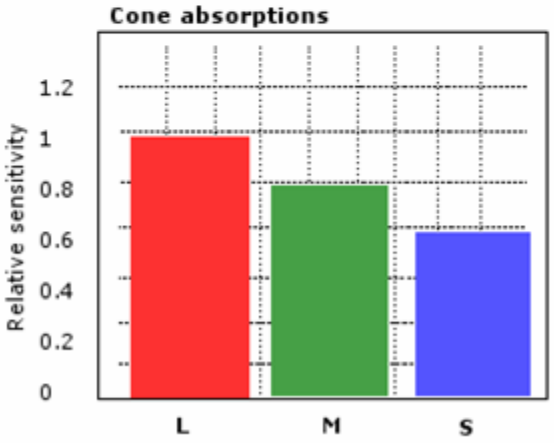
Factors of color vision





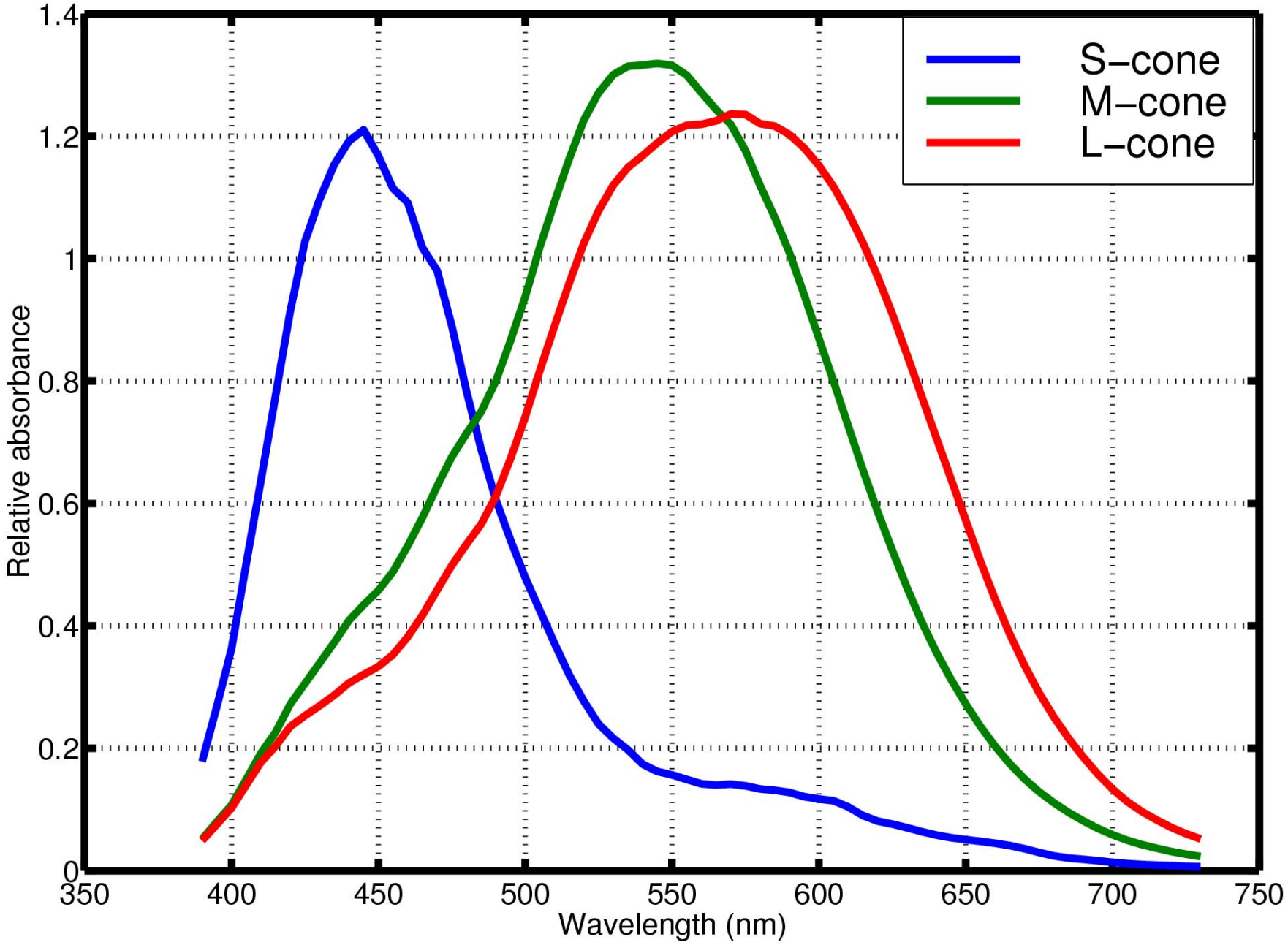


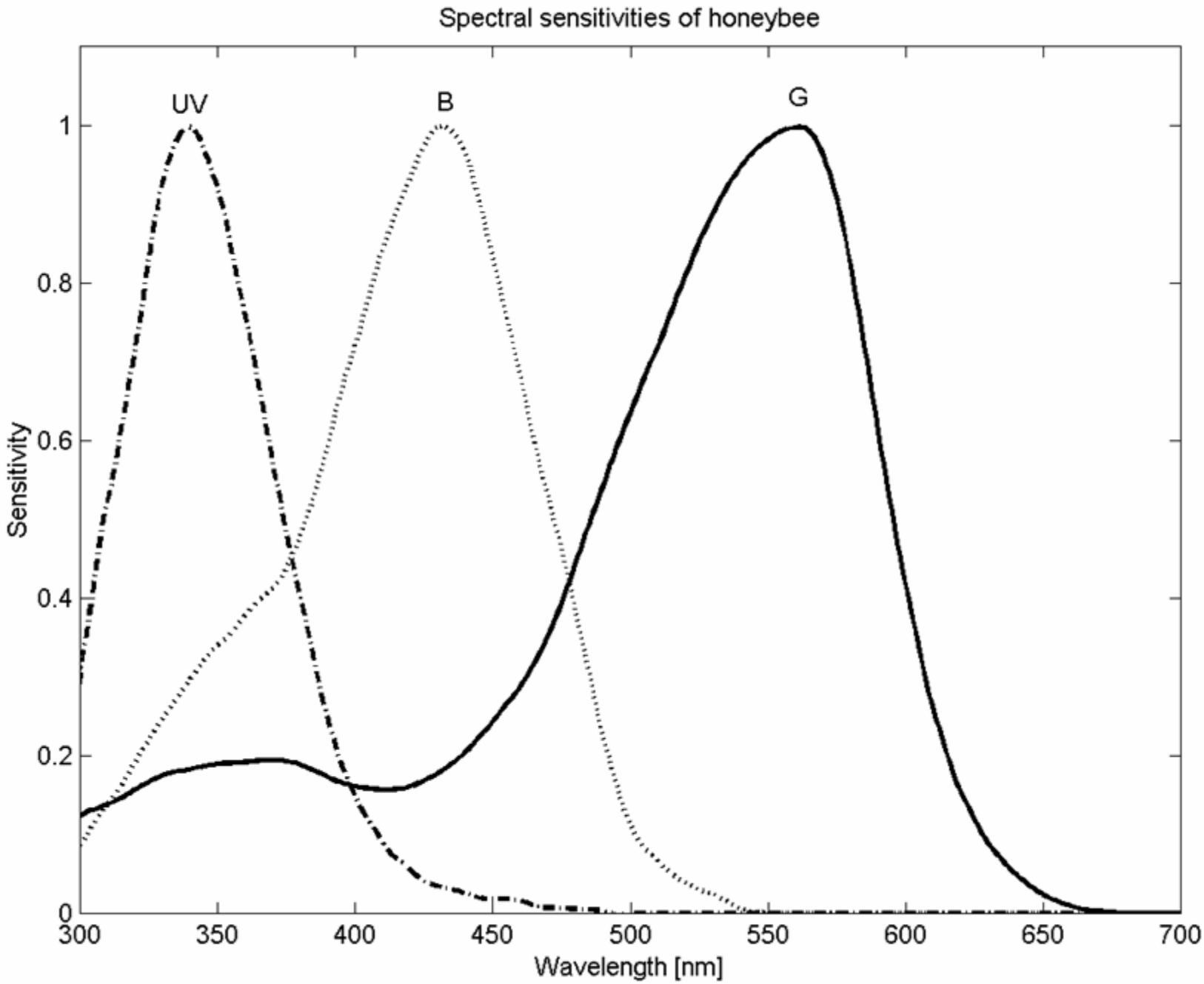


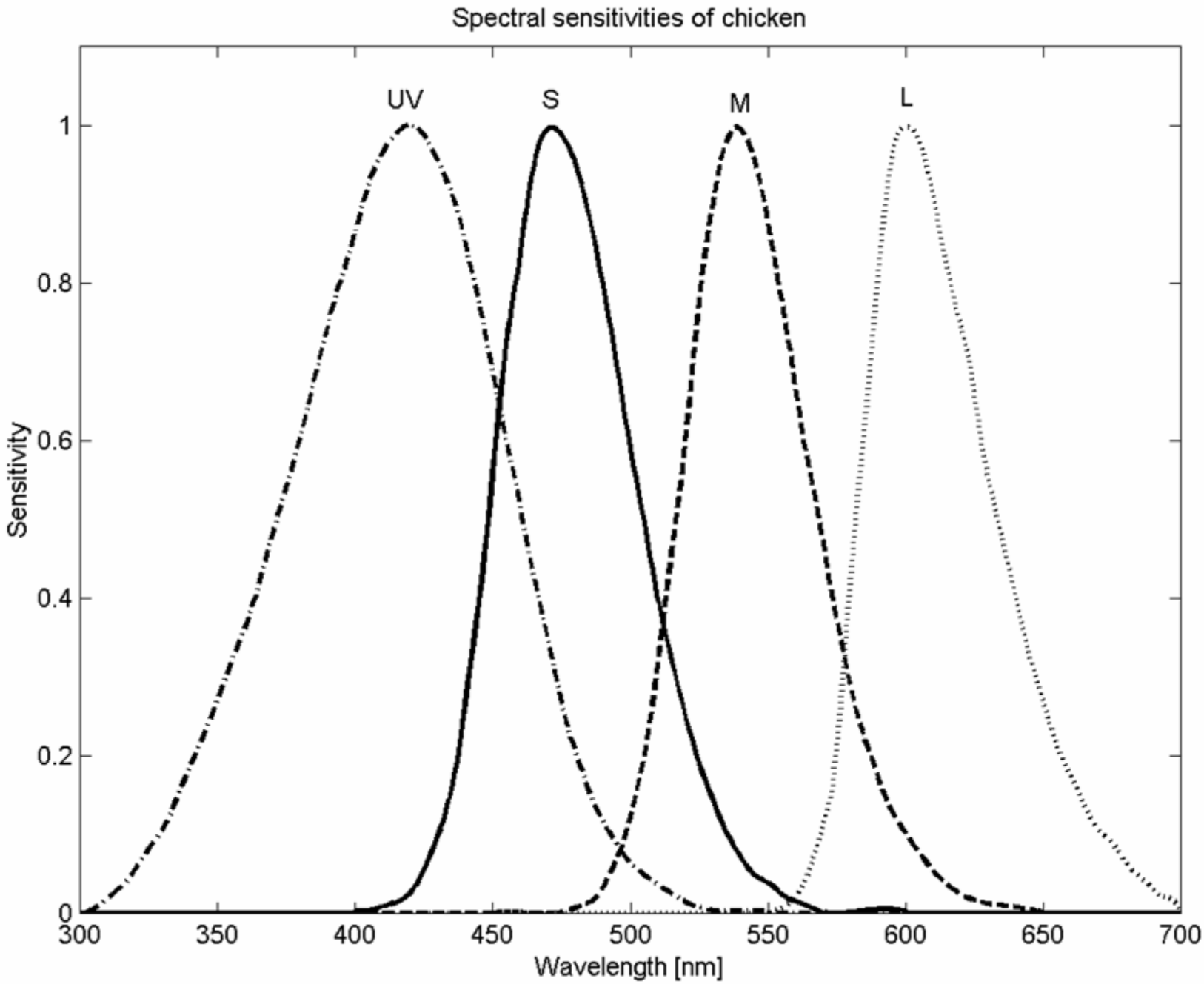


Human Color Vision System

- detection of color signal
  - cones (and rods) in retina
- preprocessing in retina
  - horisontal cells, amakrine cells, bipolar cells, . . .
- LGN (6 layers)
- visual cortex (10^8 cells)
  - other cortical areas

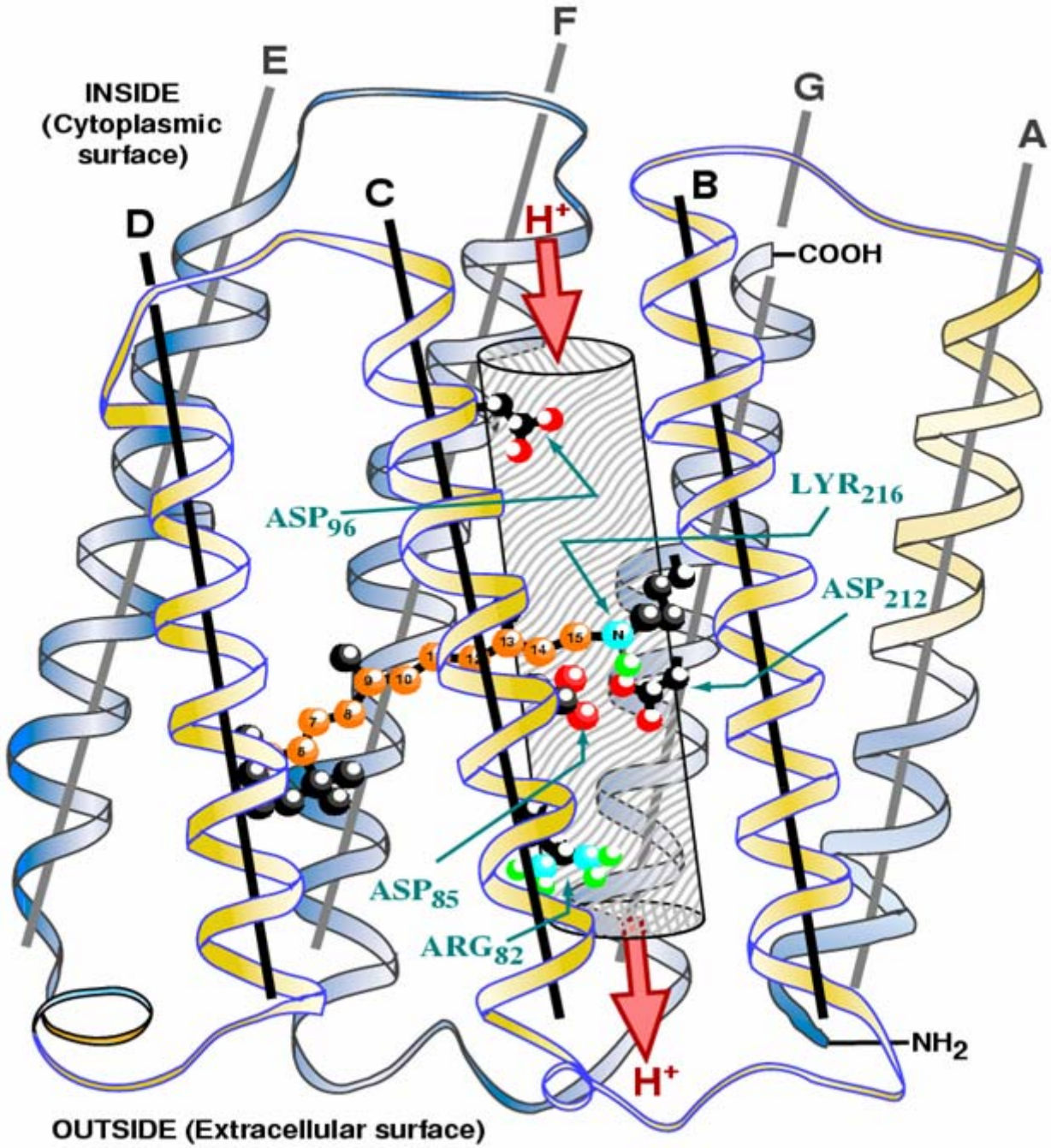

S–cone
M–cone
L–cone
Relative absorbance
Wavelength (nm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
350
400
450
500
550
600
650
700
750

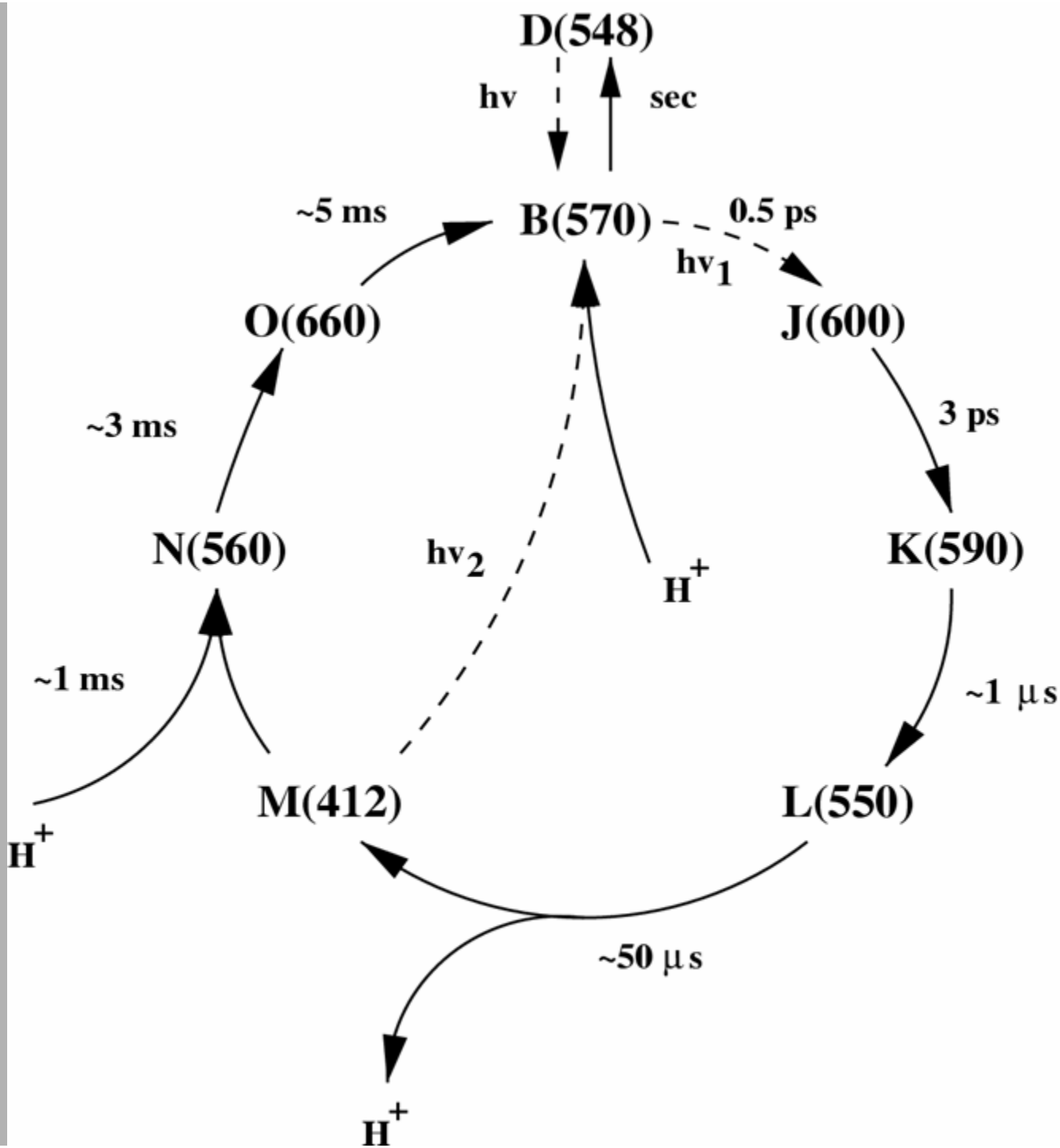

Spectral sensitivities of honeybee
UV
B
G
Sensitivity
Wavelength [nm]
0
0.2
0.4
0.6
0.8
1
300
350
400
450
500
550
600
650
700


Spectral sensitivities of chicken
UV
S
M
L
Sensitivity
Wavelength [nm]
0
0.2
0.4
0.6
0.8
1
300
350
400
450
500
550
600
650
700

Bacteriorhodopsin

- Membrane protein of *Halobacterium salinarium* bacterium
- *Halobacterium salinarium* grow in very salty waters
- Oesterhelt ja Stoeckenius extracted 1974


INSIDE
(Cytoplasmic
surface)
E
F
G
A
D
C
B
H+
COOH
ASP96
LYR216
ASP212
ASP85
ARG82
NH2
H+
OUTSIDE (Extracellular surface)


D(548)
hv
sec
~5 ms
B(570)
0.5 ps
hv1
O(660)
J(600)
~3 ms
3 ps
N(560)
hv2
H+
K(590)
~1 ms
~1 μs
M(412)
L(550)
H+
~50 μs
H+

Why bacteriorhodopsin (1/2)?

- fotoactiv
  - fotochromic
  - fotoelectric
- stabile rhodopsin
- long lifetime
- relatively easy to produce
- spectral sensitivity modifiable

Why bacteriorhodopsin (2/2)?

- > 10^6 repeatable fotocycle
- accuracy > 5000 lines/mm
- quantum efficiency 0.64 (B->J)
- stable when
  - temperature < 80 C
  - 3 < pH < 10

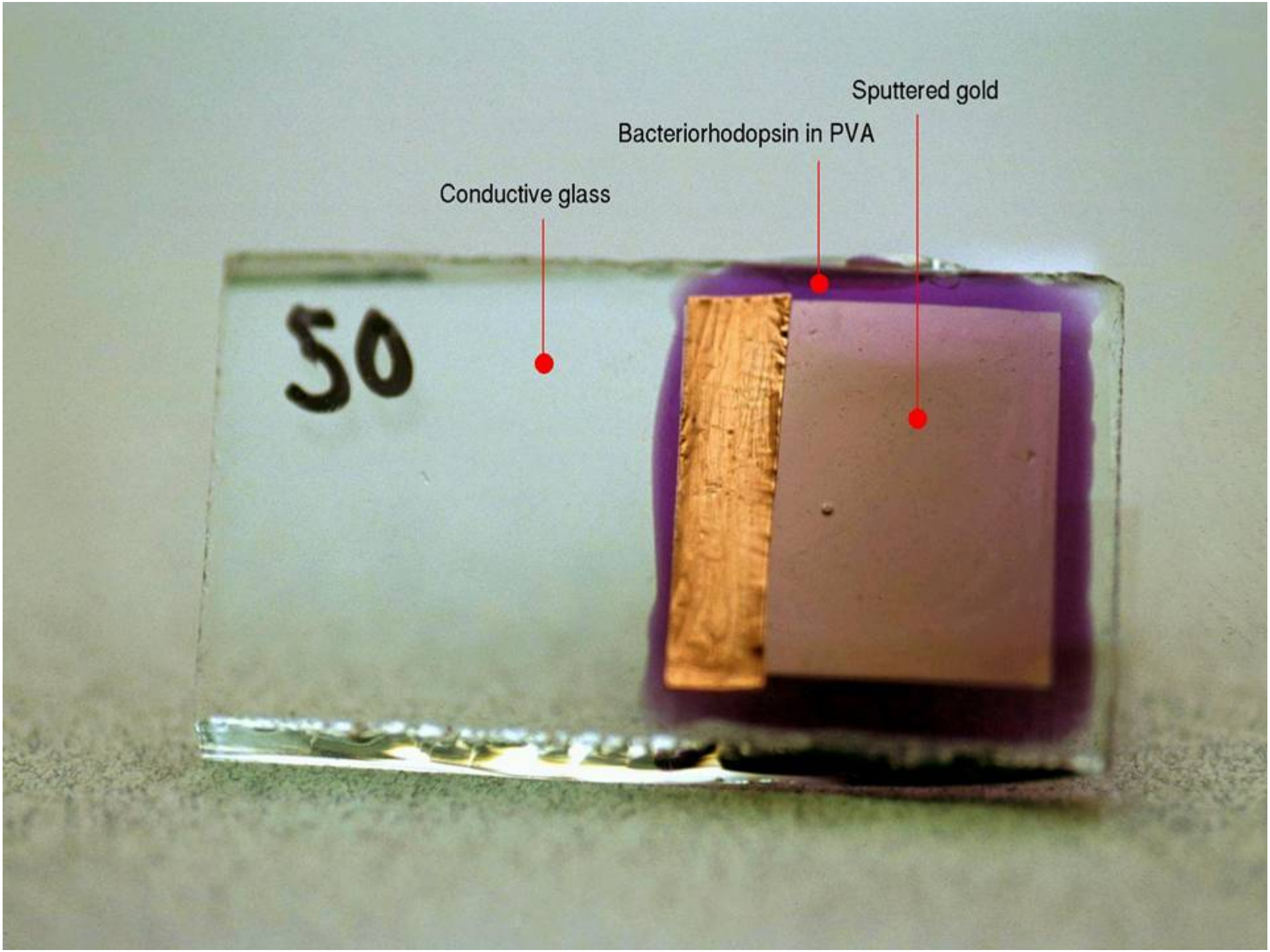
Bacteriorhodopsin

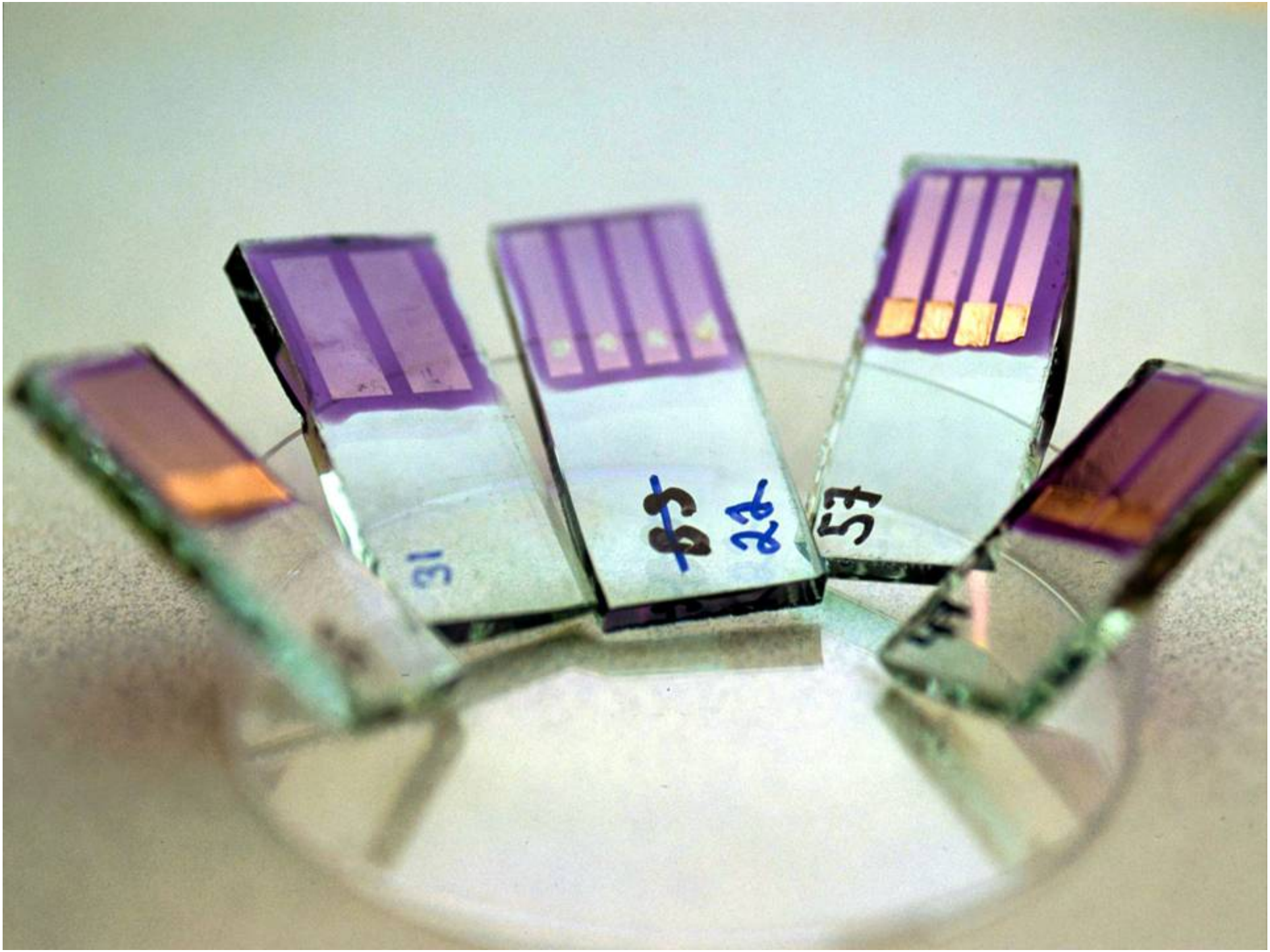
- Optical 3D memory — *Birge*
- Optical memorymedia — *Hampp*
- Optical sensorymatrix — *Koyama et al.*
- Colorsensor — *LTY & JoY*

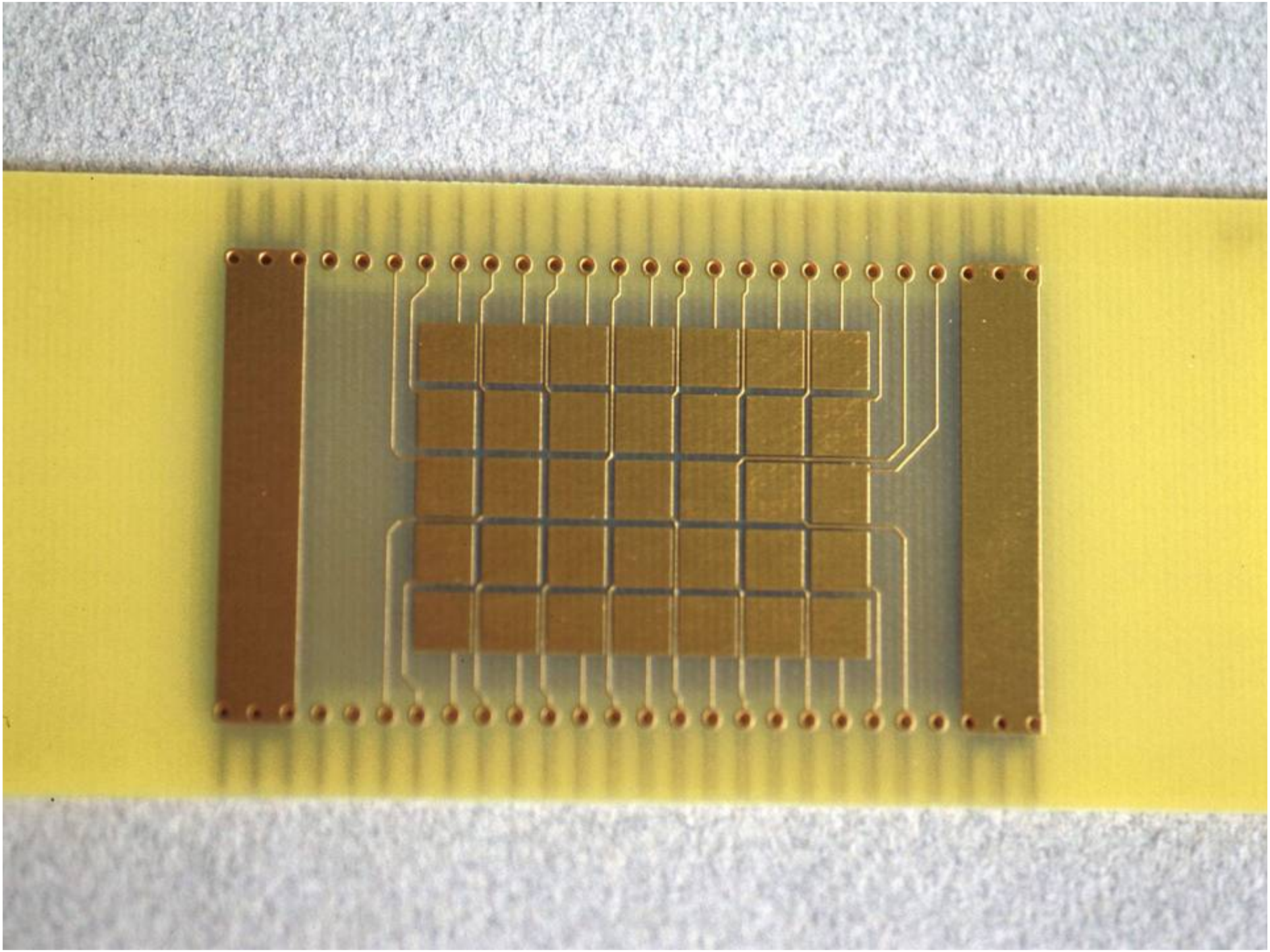
Preparation of BR/PVA-films

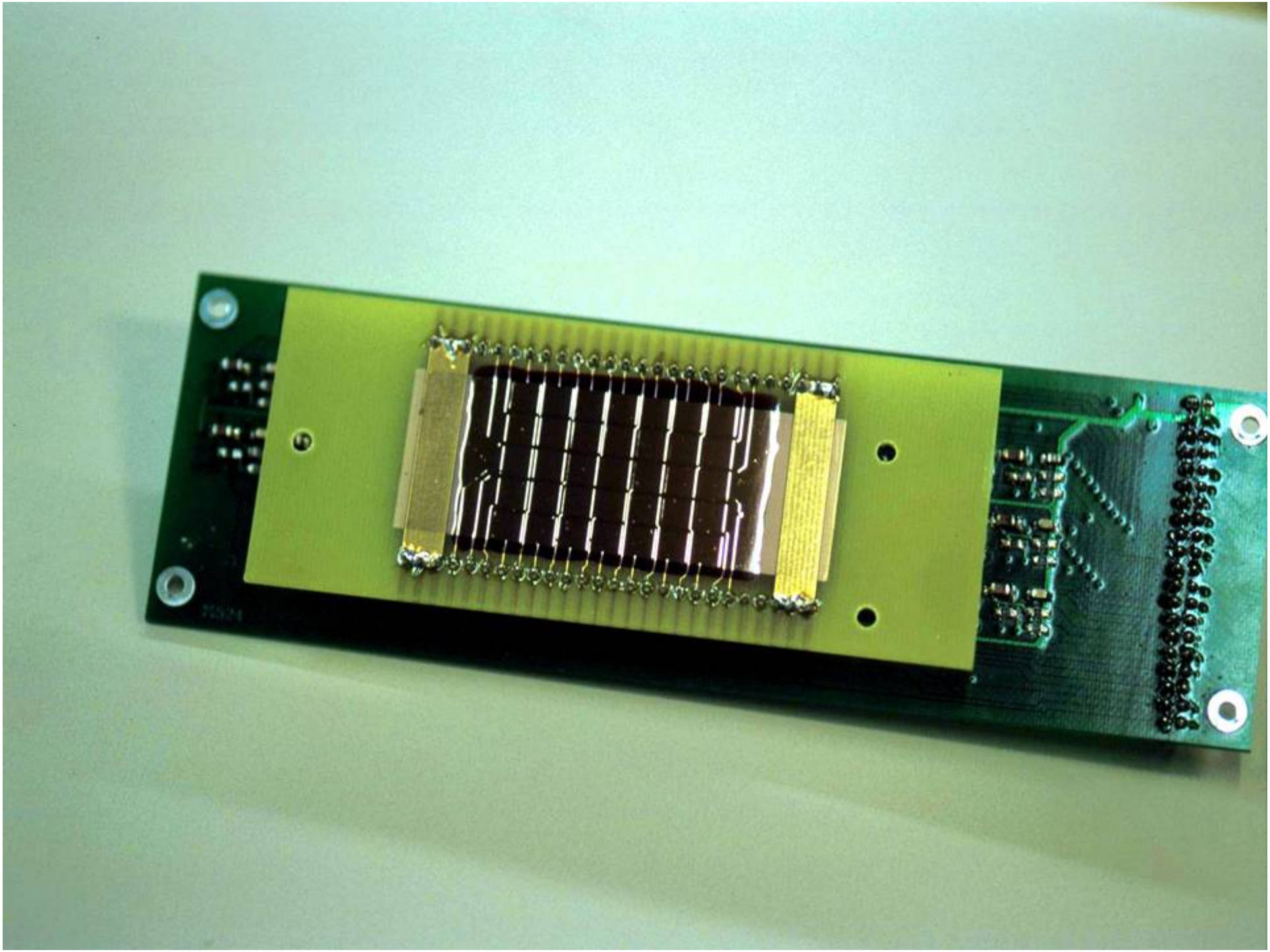
purplemembrane is used

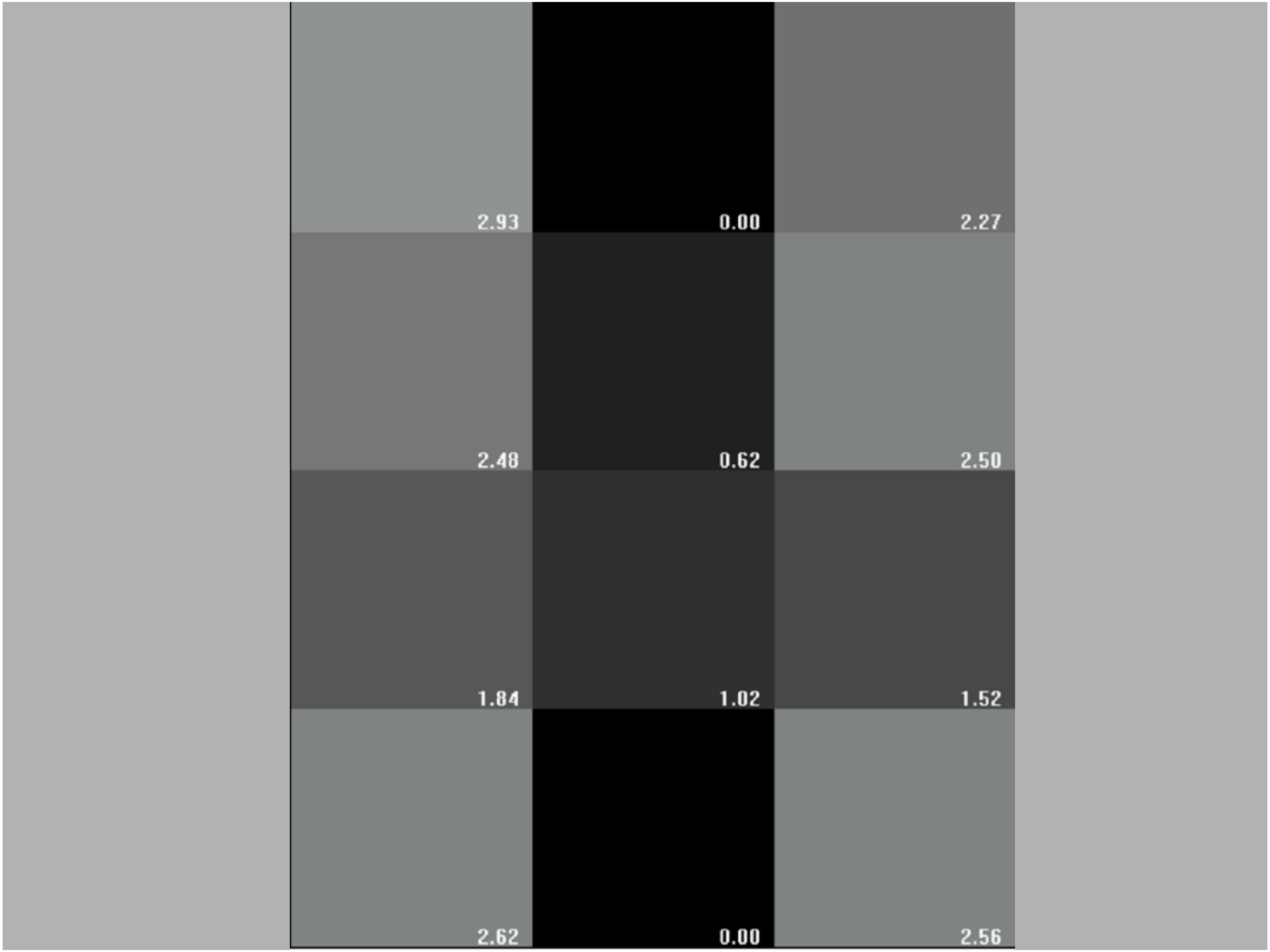
1. mix polyvinylalcohol (PVA) with BR-solution
2. spread mixture on conductive glass
3. dry 24 hours
4. sputter gold leyer on the film as counter electrode

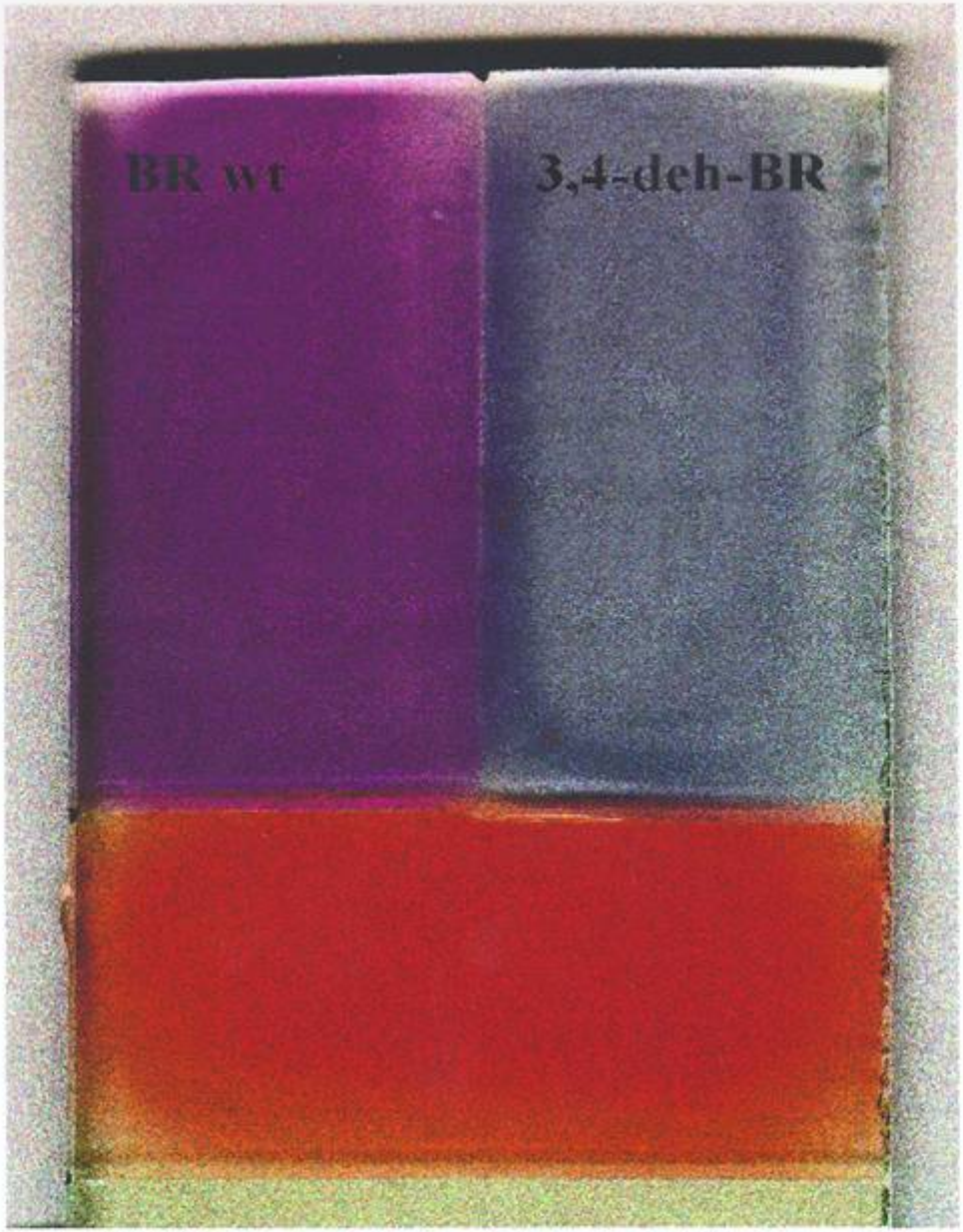

Sputtered gold
Bacteriorhodopsin in PVA
Conductive glass
50

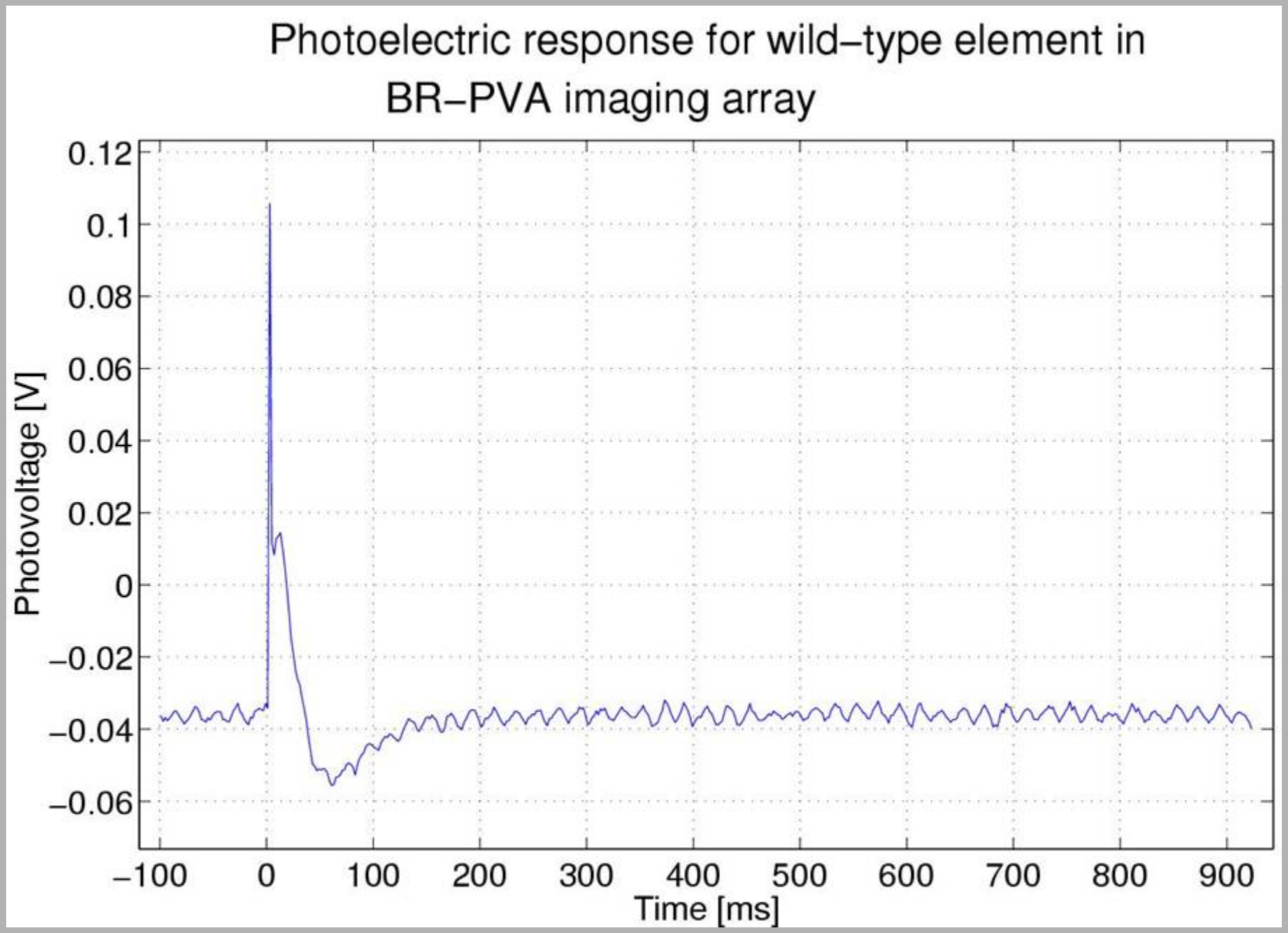

31
24
54

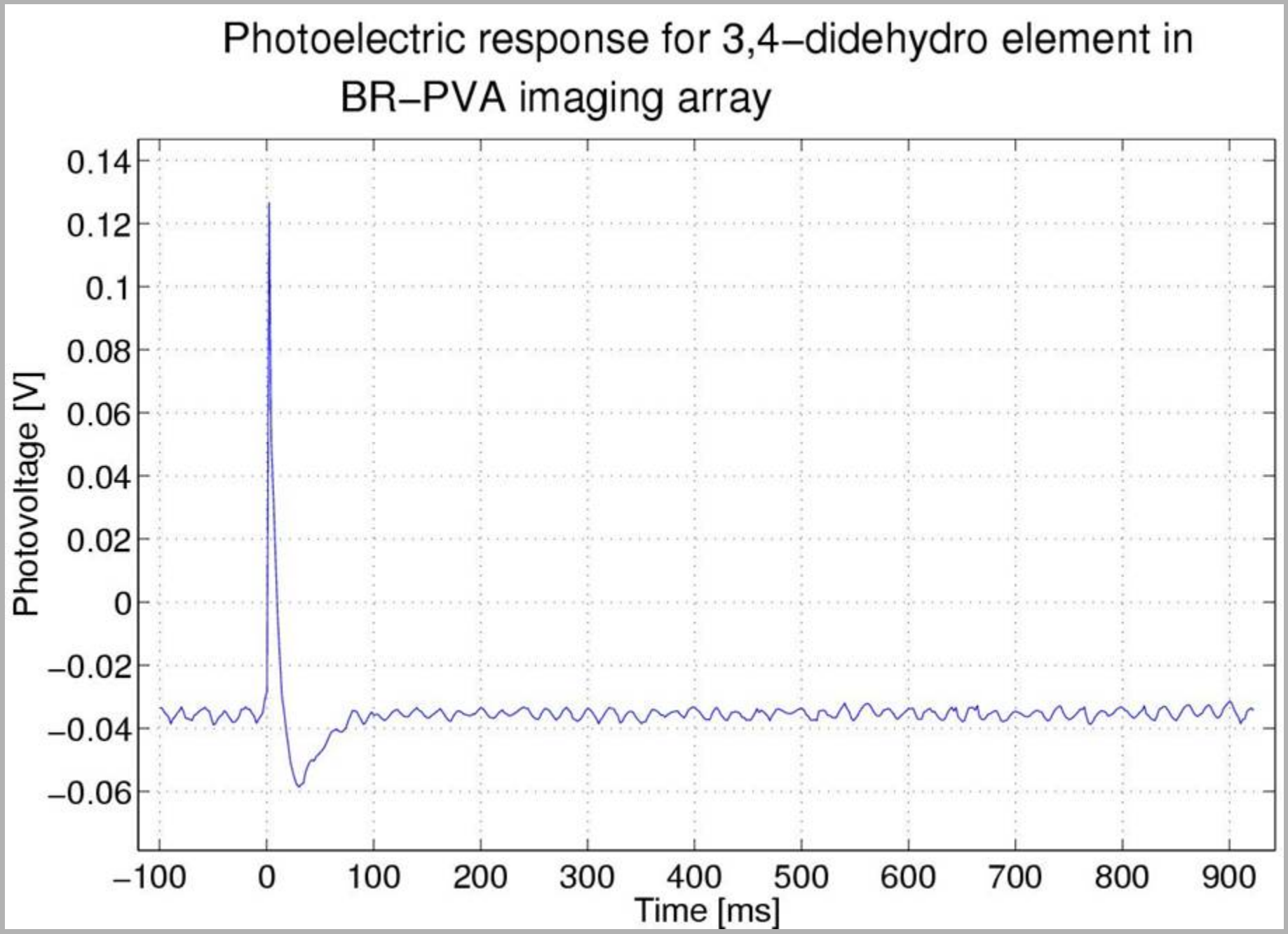


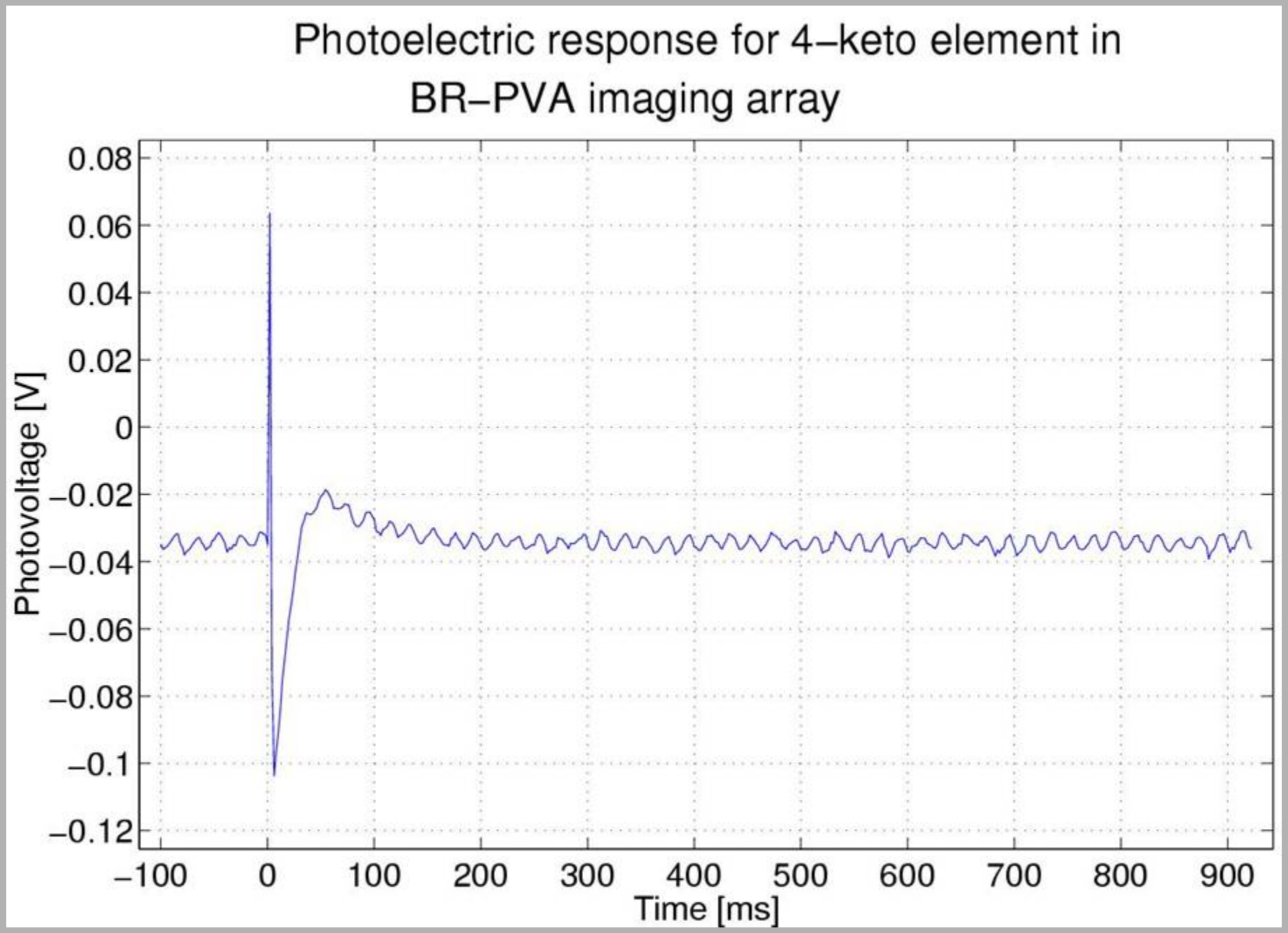


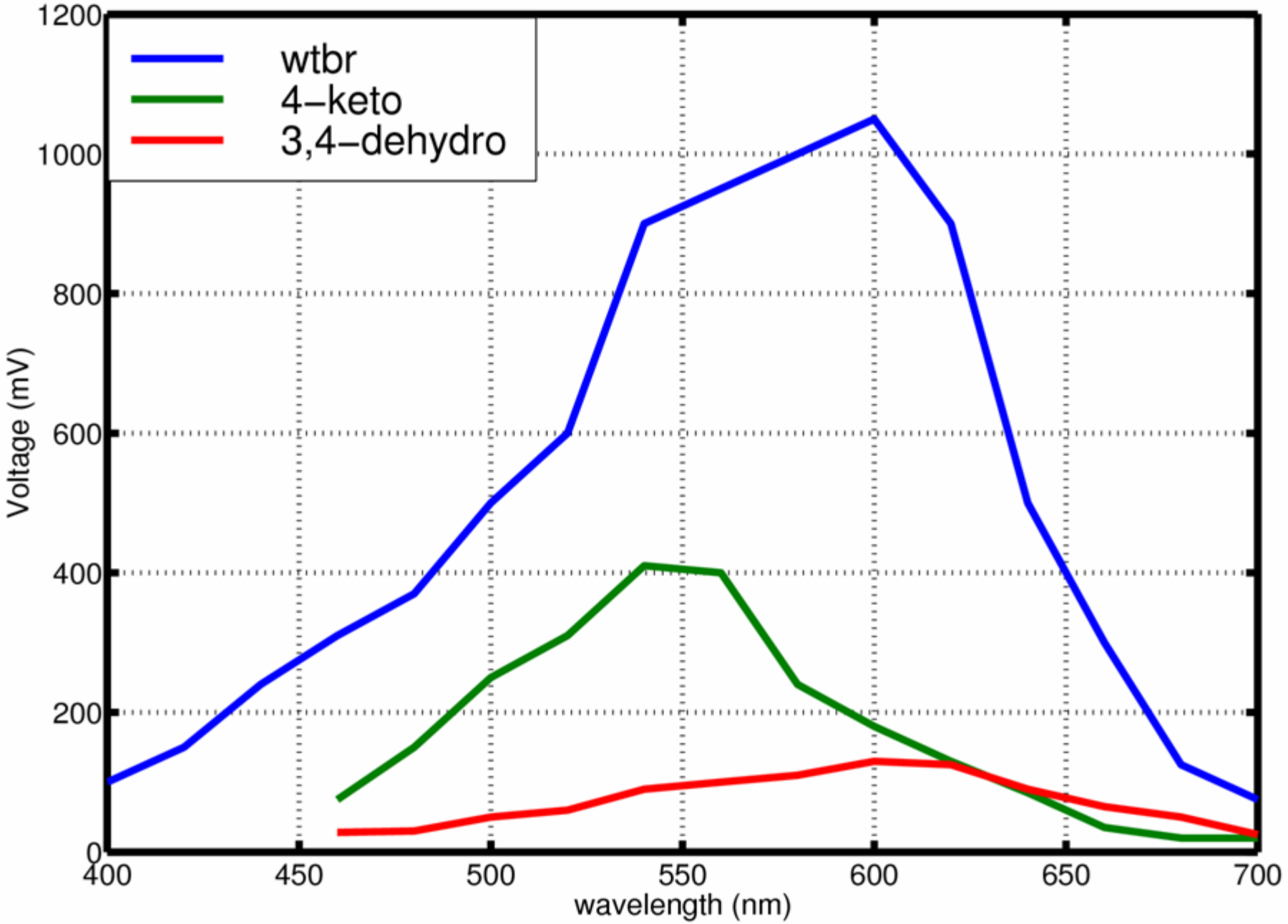

2.93
0.00
2.27
2.48
0.62
2.50
1.84
1.02
1.52
2.62
0.00
2.56

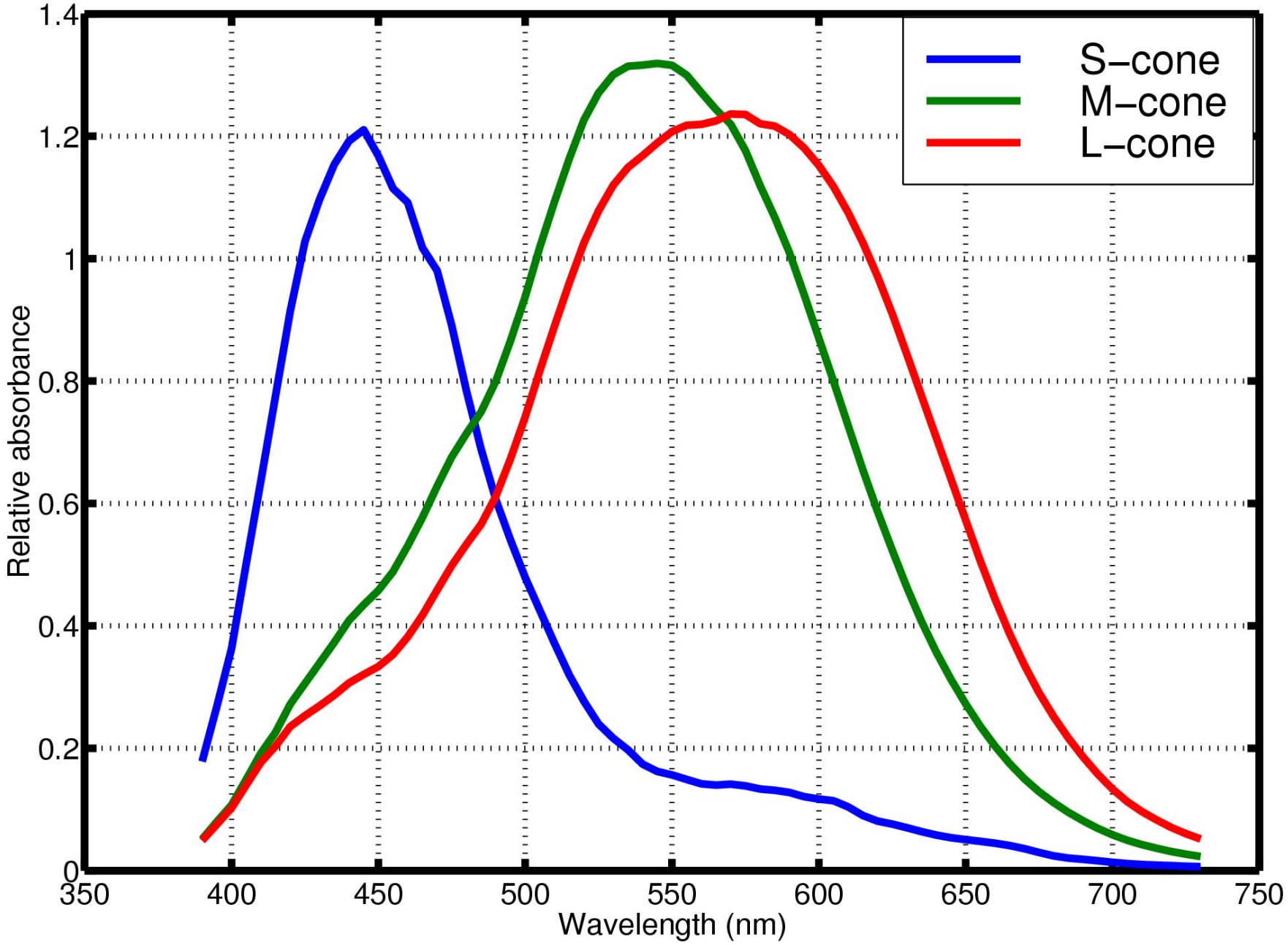

BR wt
3,4-deh-BR

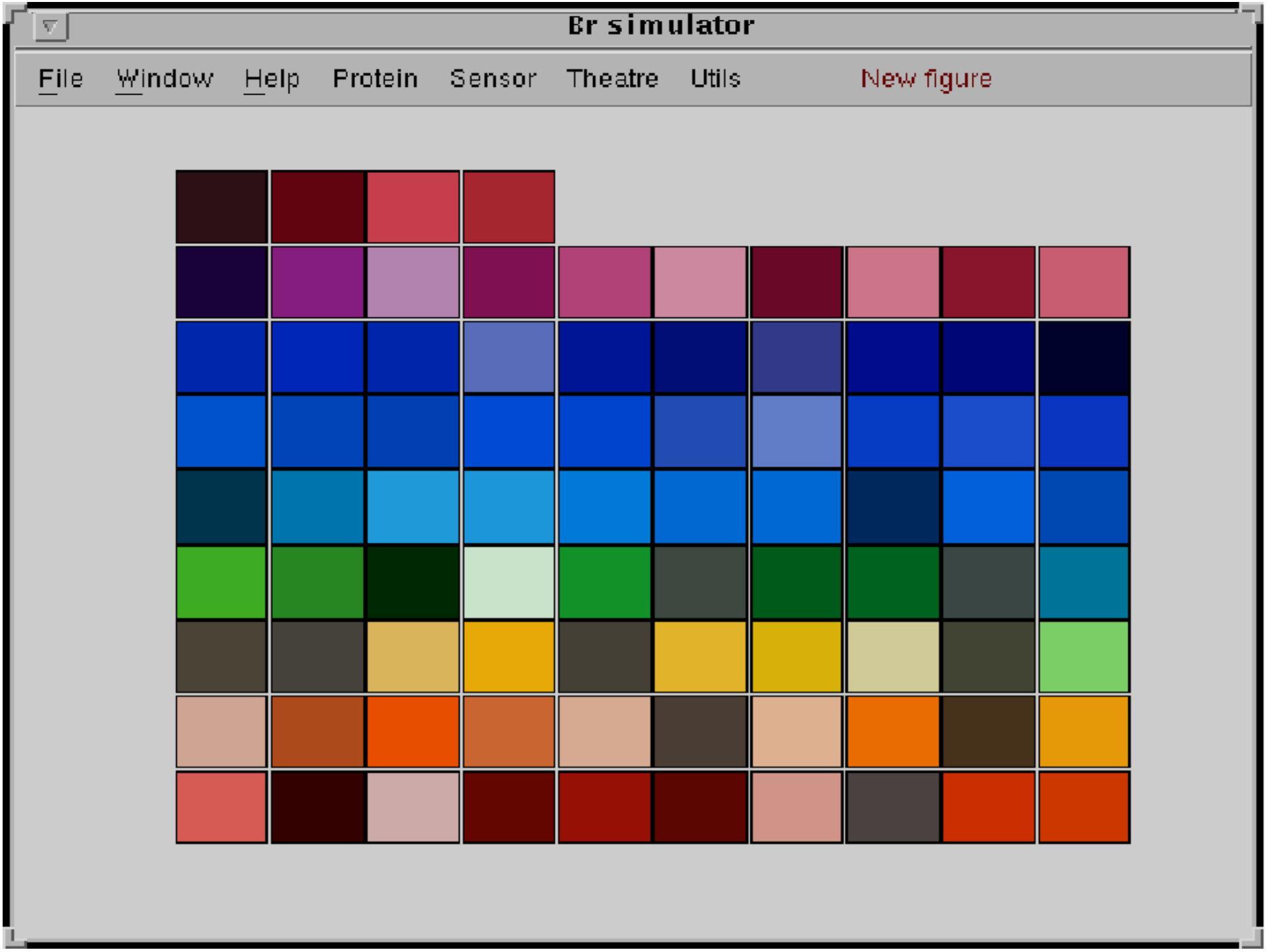

Photoelectric response for wild–type element in
BR–PVA imaging array
Photovoltage [V]
0.12
0.1
0.08
0.06
0.04
0.02
0
–0.02
–0.04
–0.06
–100
0
100
200
300
400
500
600
700
800
900
Time [ms]


Photoelectric response for 3,4–didehydro element in BR–PVA imaging array
Photovoltage [V]
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
–0.02
–0.04
–0.06
–100
0
100
200
300
400
500
600
700
800
900
Time [ms]


Photoelectric response for 4–keto element in
BR–PVA imaging array
Photovoltage [V]
0.08
0.06
0.04
0.02
0
–0.02
–0.04
–0.06
–0.08
–0.1
–0.12
–100
0
100
200
300
400
500
600
700
800
900
Time [ms]

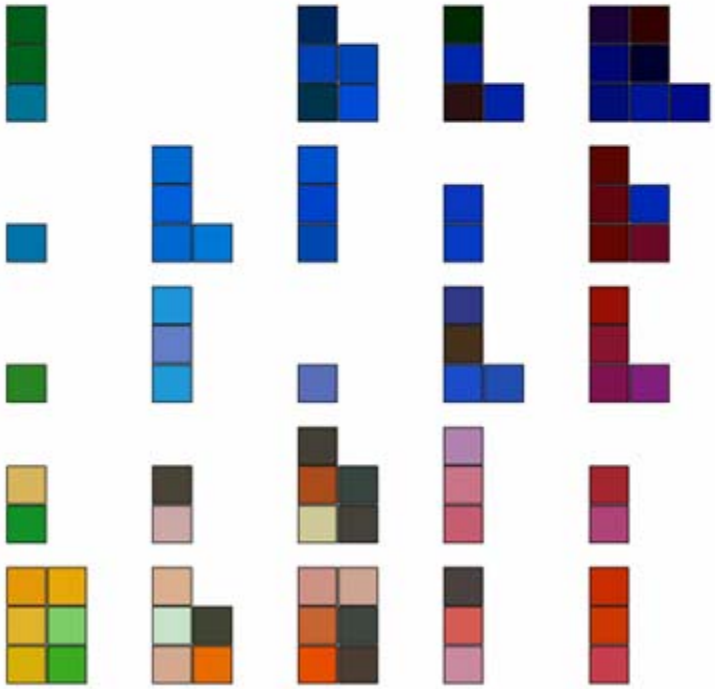

wtbr
4–keto
3,4–dehydro
Voltage (mV)
wavelength (nm)
0
200
400
600
800
1000
1200
400
450
500
550
600
650
700

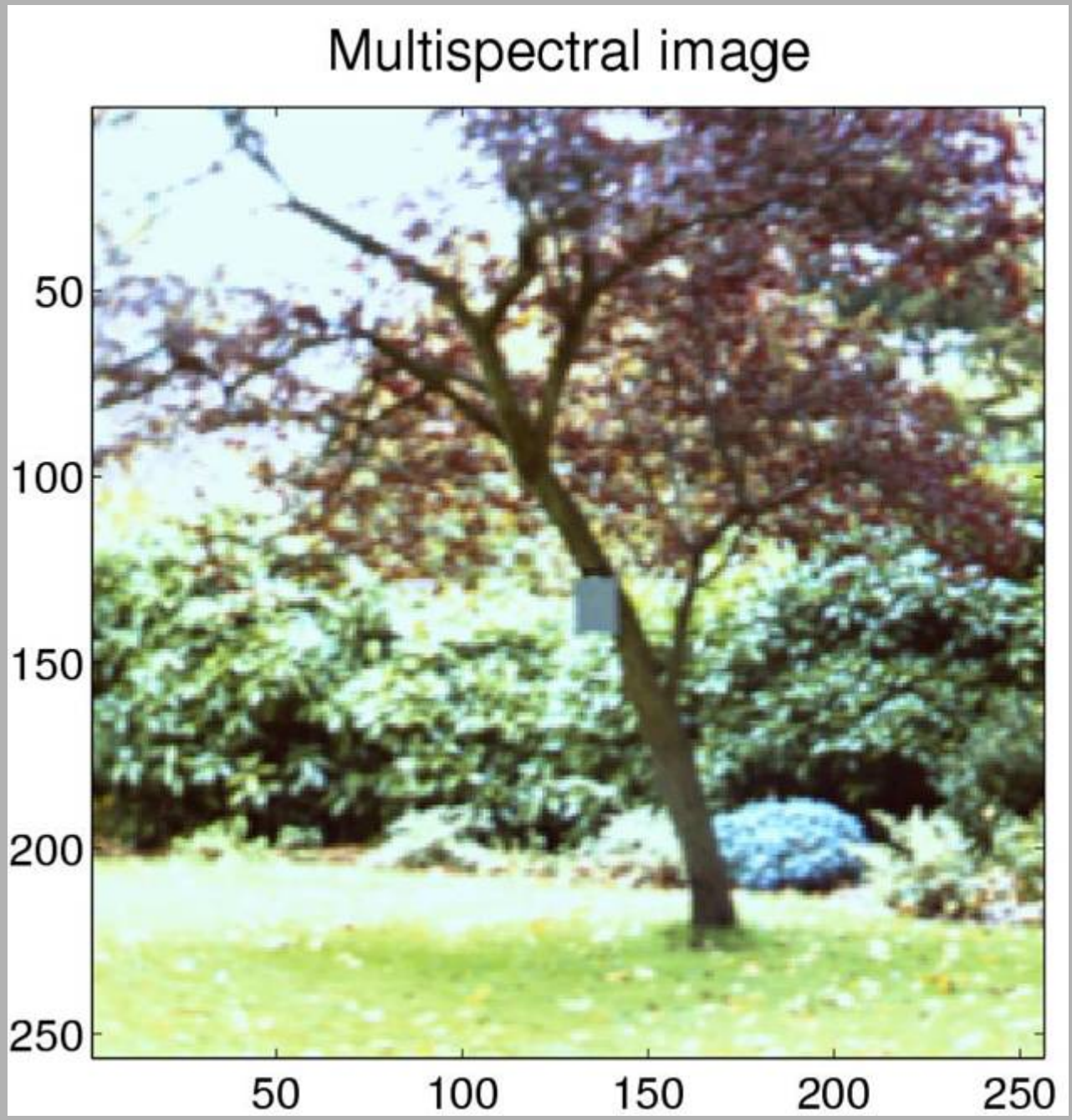

S–cone
M–cone
L–cone
Relative absorbance
Wavelength (nm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
350
400
450
500
550
600
650
700
750

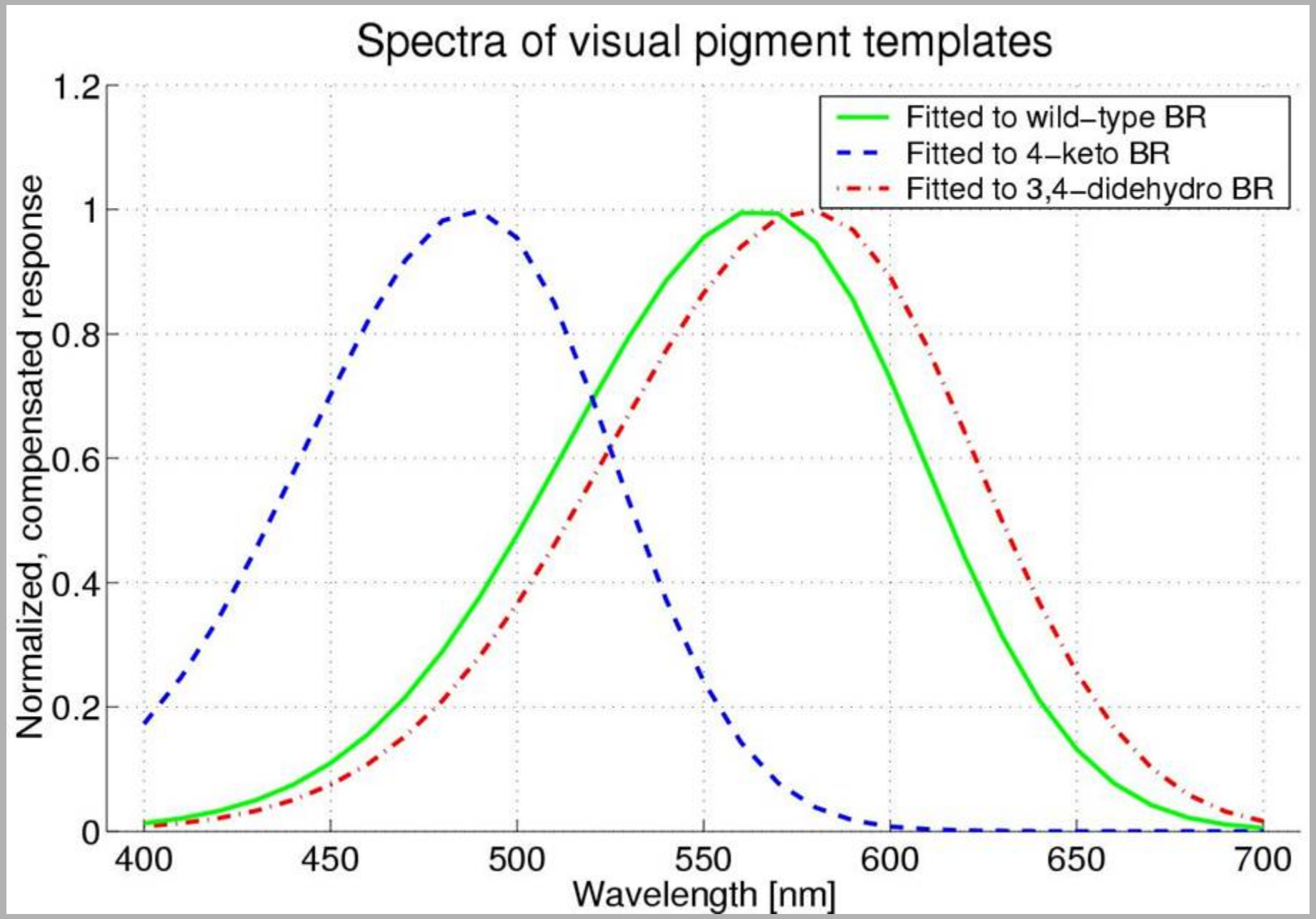

Br simulator
File
Window
Help
Protein
Sensor
Theatre
Utils
New figure

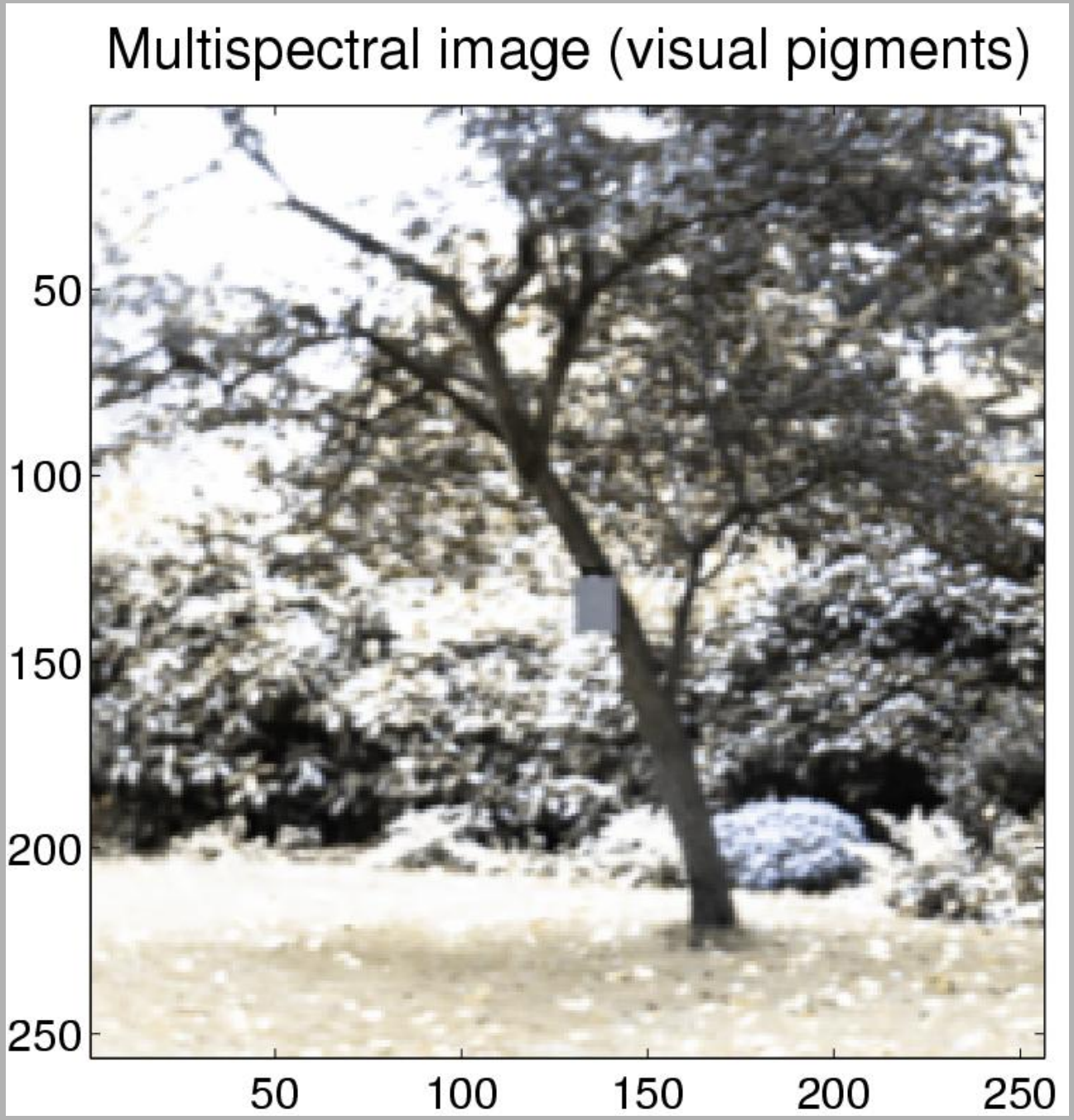
Example of training SOM - result

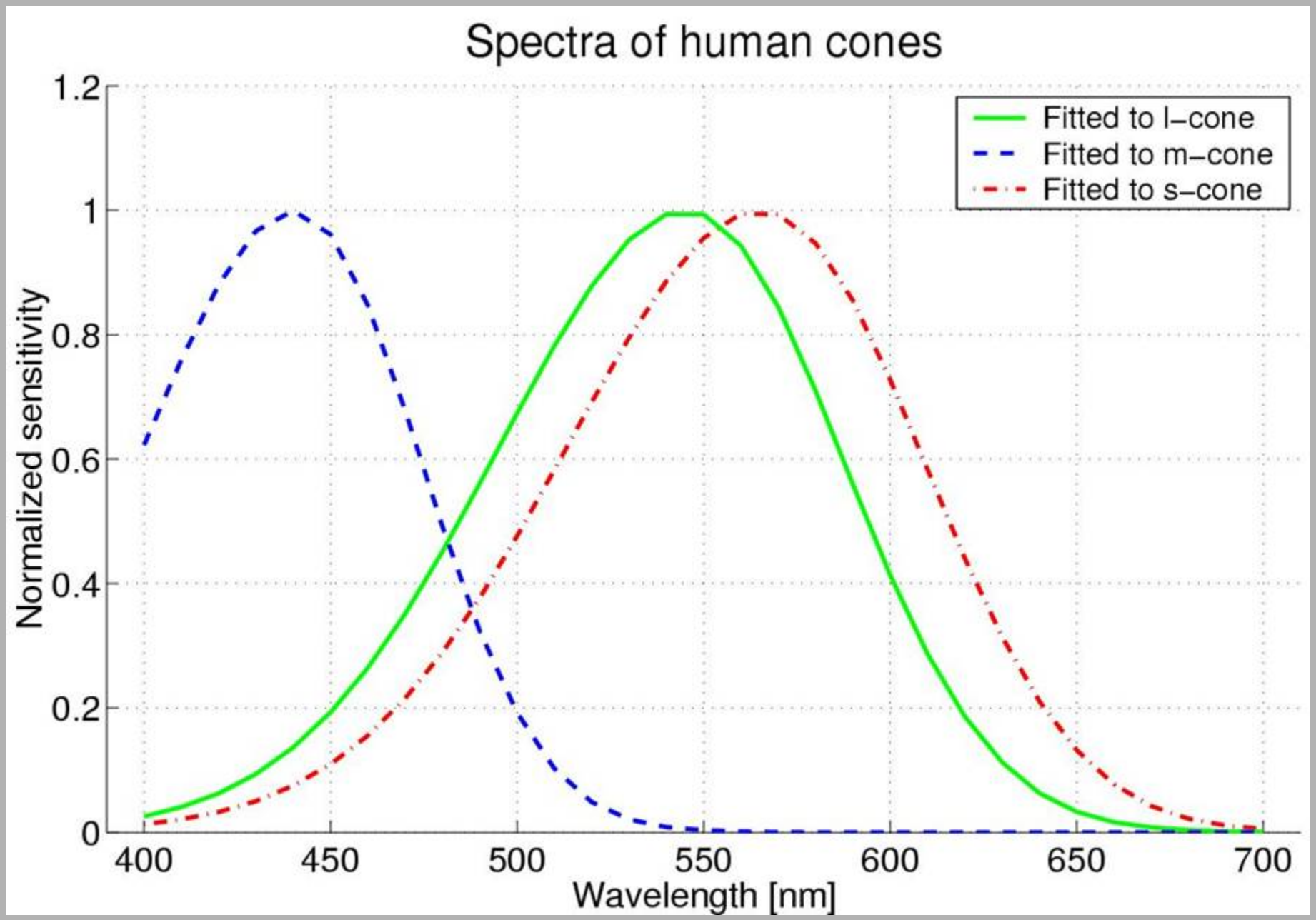
After the training has finished (100000 training steps)

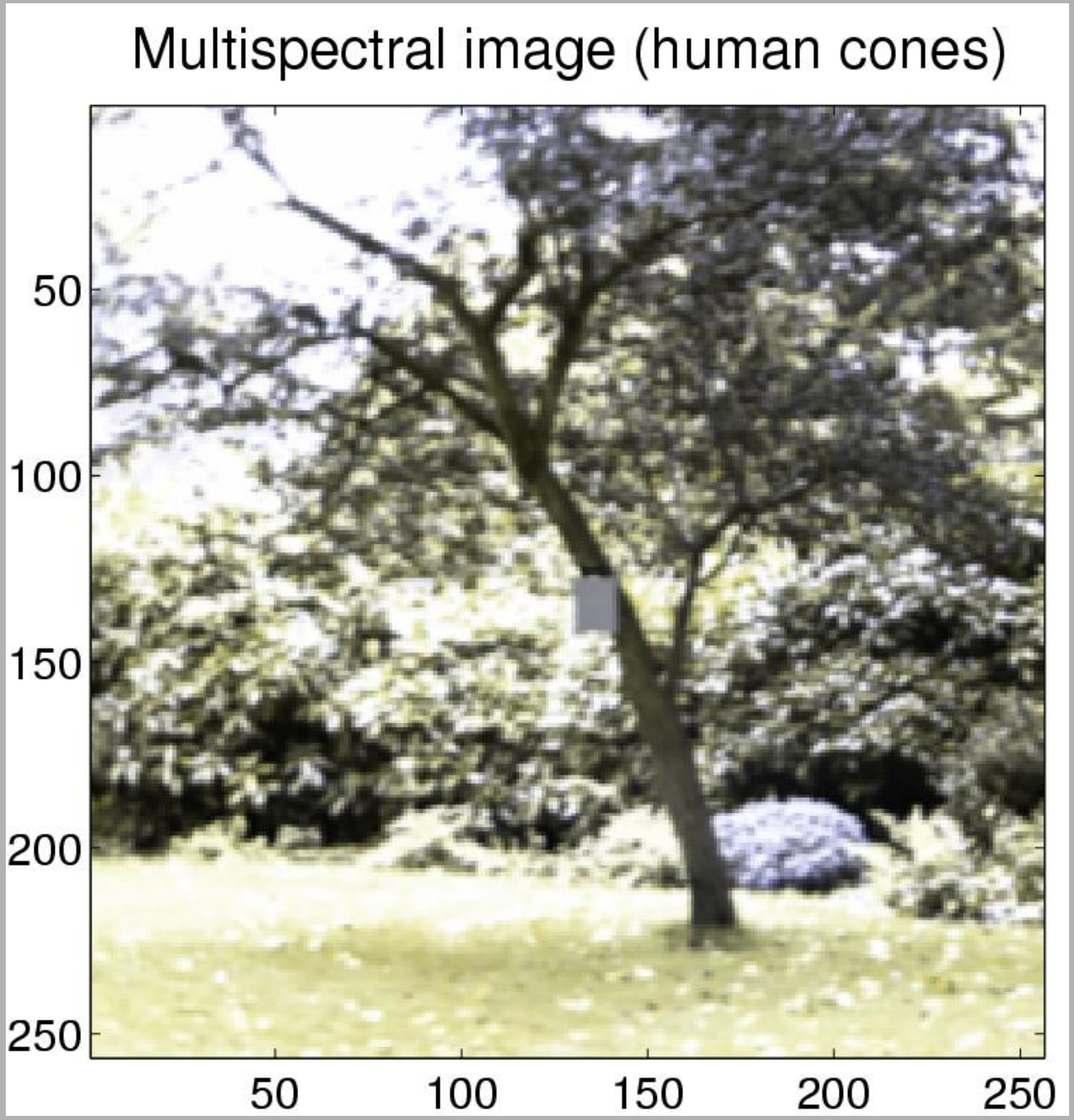


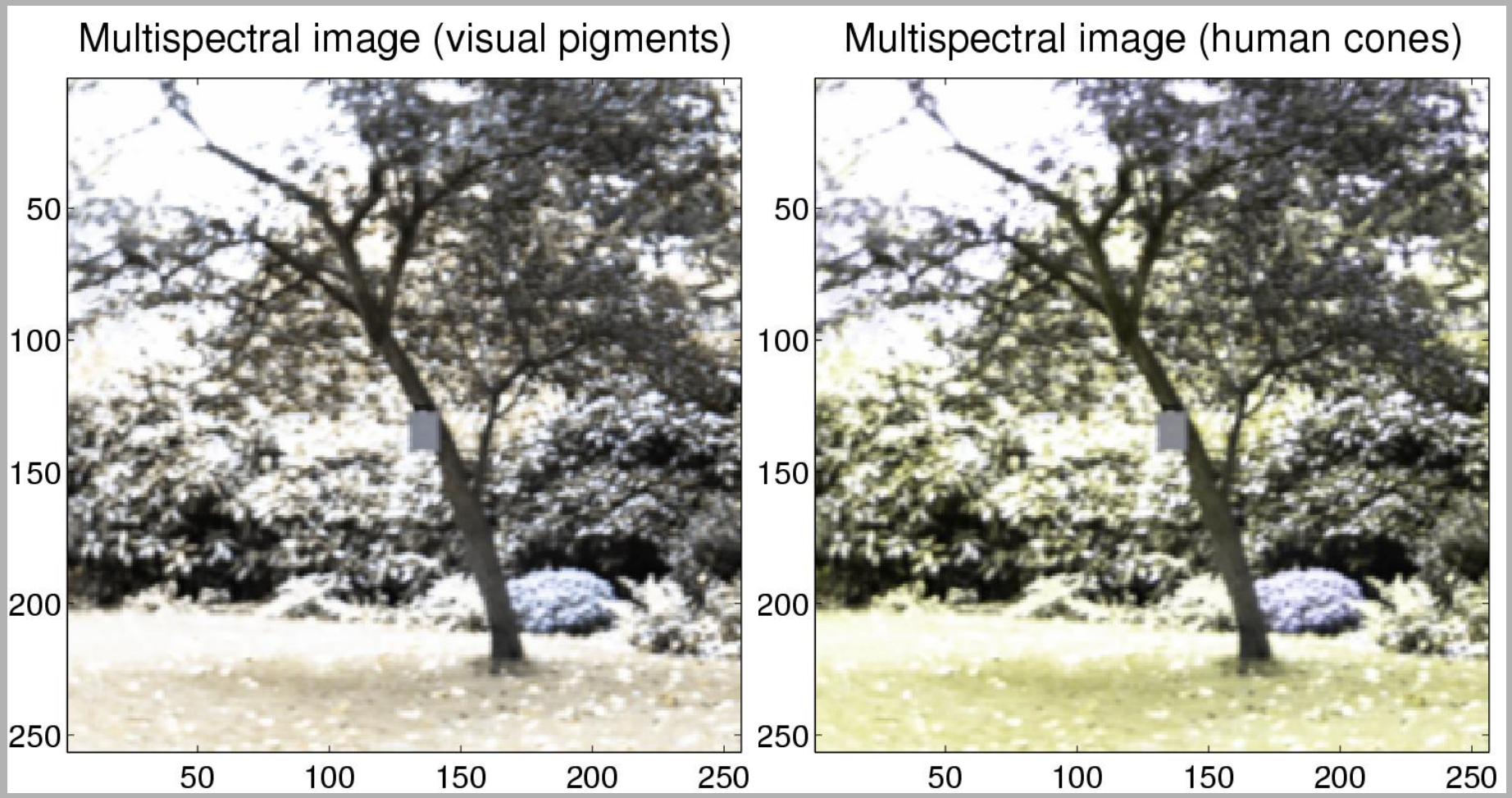

Multispectral image
50
100
150
200
250
50
100
150
200
250


Spectra of visual pigment templates
Fitted to wild−type BR
Fitted to 4−keto BR
Fitted to 3,4−didehydro BR
Normalized, compensated response
Wavelength [nm]
0
0.2
0.4
0.6
0.8
1
1.2
400
450
500
550
600
650
700

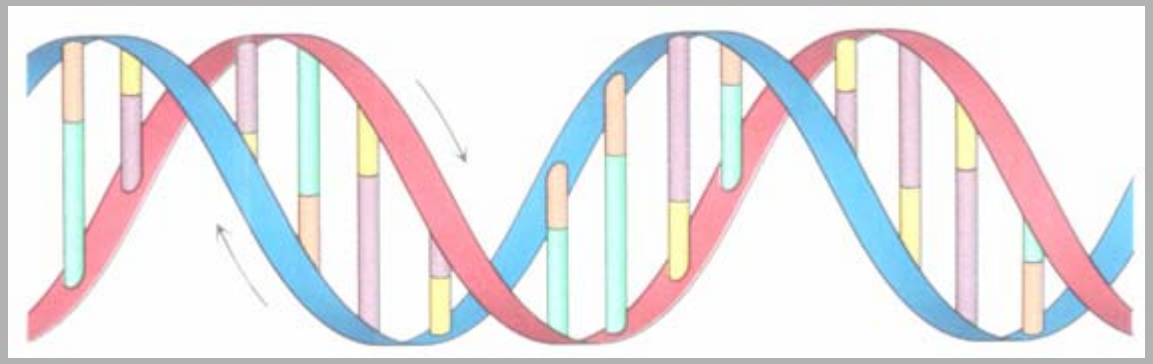

Multispectral image (visual pigments)
50
100
150
200
250
50
100
150
200
250


Spectra of human cones
Fitted to l−cone
Fitted to m−cone
Fitted to s−cone
Normalized sensitivity
Wavelength [nm]
0
0.2
0.4
0.6
0.8
1
1.2
400
450
500
550
600
650
700


Multispectral image (human cones)
50
100
150
200
250
50
100
150
200
250


Multispectral image (visual pigments)
Multispectral image (human cones)
50
100
150
200
250
50
100
150
200
250
50
100
150
200
250
50
100
150
200
250

Structure of DNA

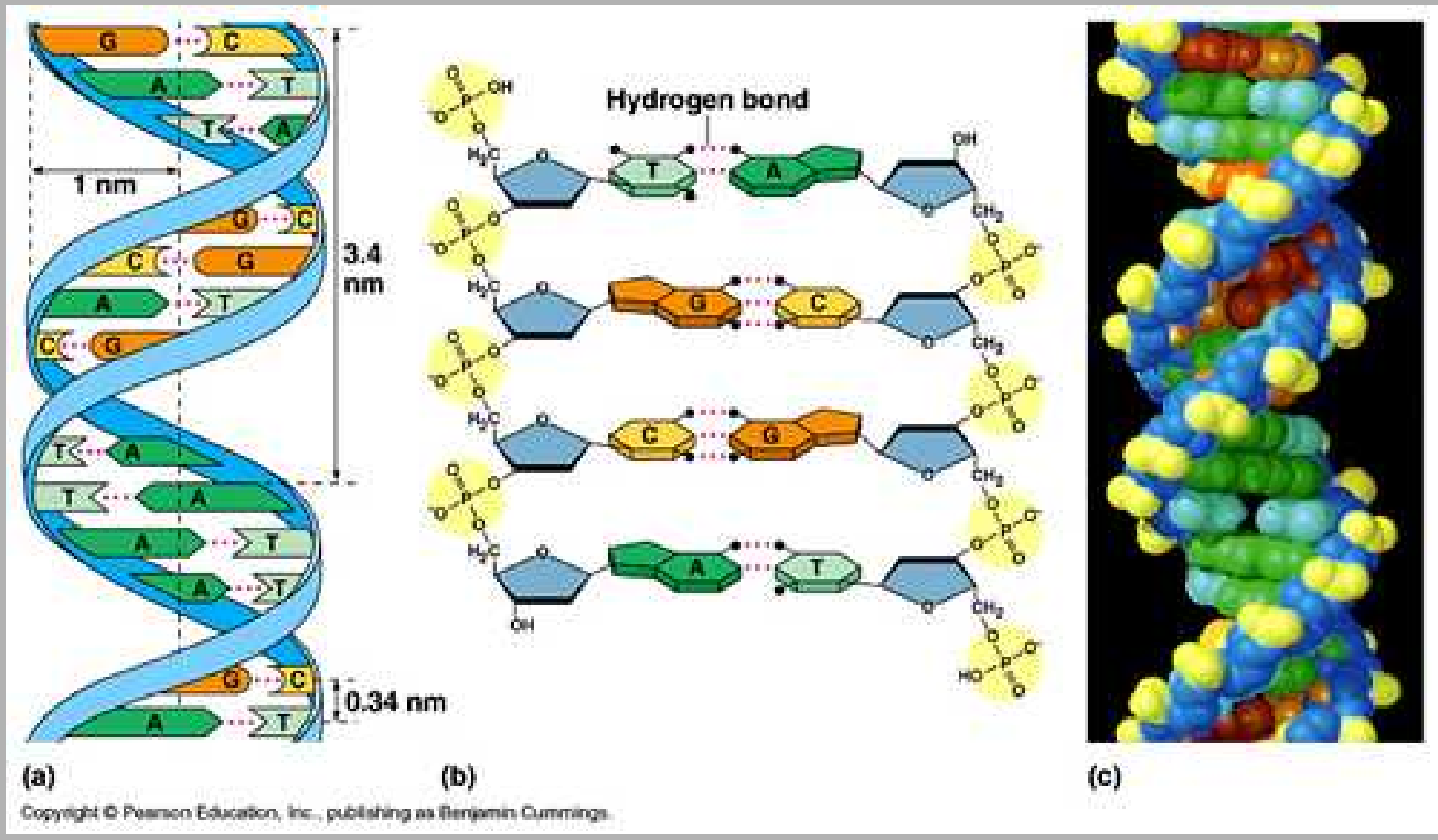


- Double Helix
- Sugar-phosphate backbones wind around the helix axis
- Bases are on the inside of the helix, stacked on top of each other like the steps of a spiral staircase

Rest of the slides are from Miki Kallio's MSc thesis and slides

DNA = deoxyribonucleic acid

- Phosphate group
- Sugar (deoxyribose)
- 4 different organic bases:
  - adenine (A)
  - cytosine (C)
  - guanine (G)
  - thymine (T)
- Genetic information is coded into the base order of DNA



Structure of DNA

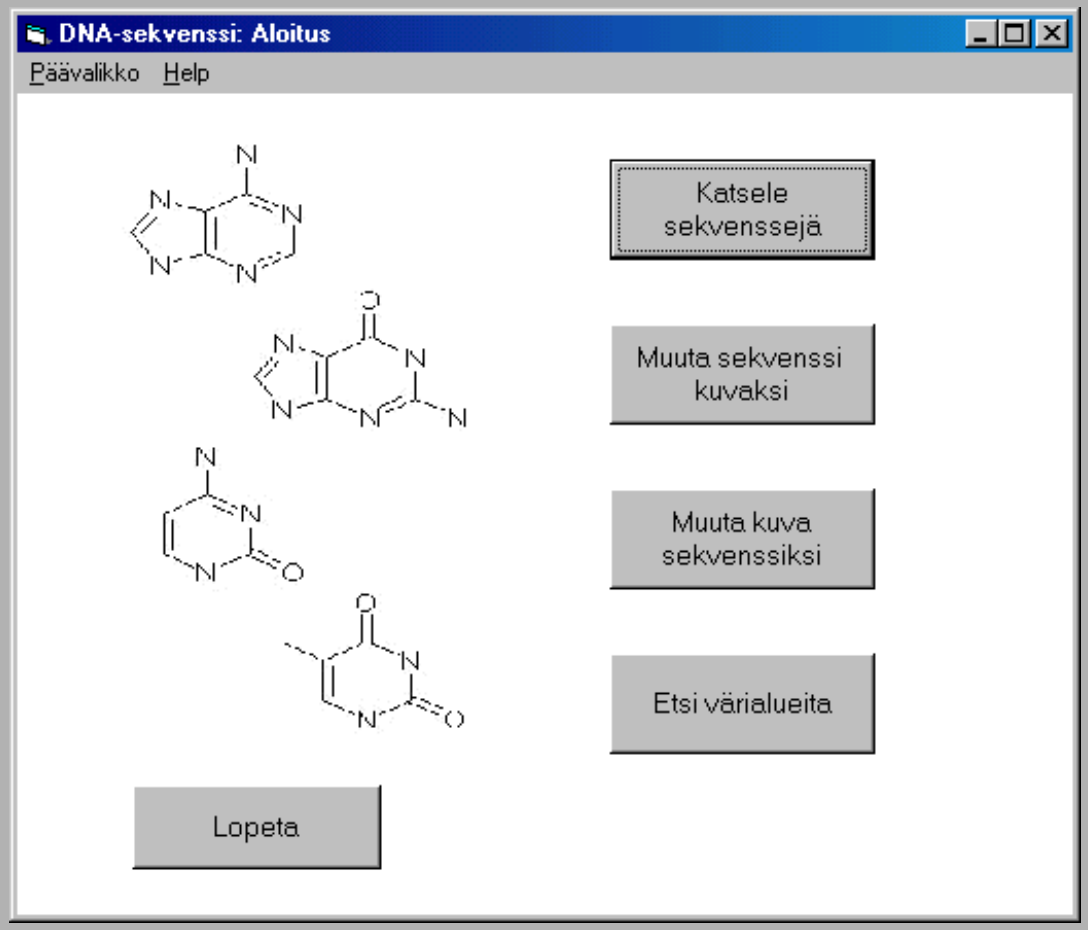
- Within the DNA double helix, A forms 2 hydrogen bonds with T on the opposite strand, and G forms 3 hydrogen bonds with C on the opposite strand
- The strands are complementary to each other: one stranded DNA can have only one particular pair strand
  - E.g. ACTTGCAG and TGAACGTC

Three steps of DNA-based methods

1. Coding of problem into DNA-sequence
2. test tube reactions
3. reading the results

ORGANIC DATA MEMORY

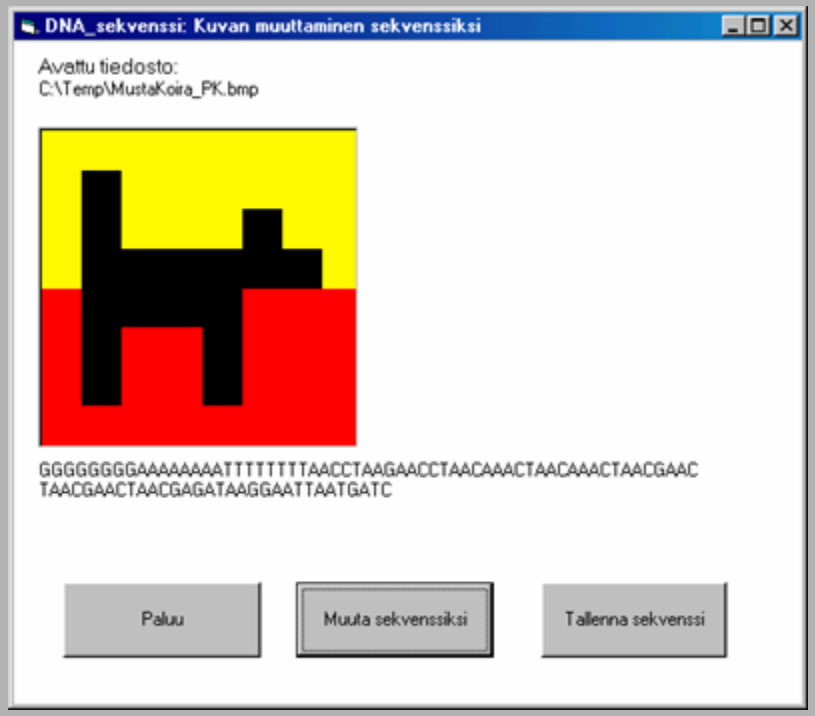
Using the DNA Approach



Introduction: Applications of Writing Information into DNA

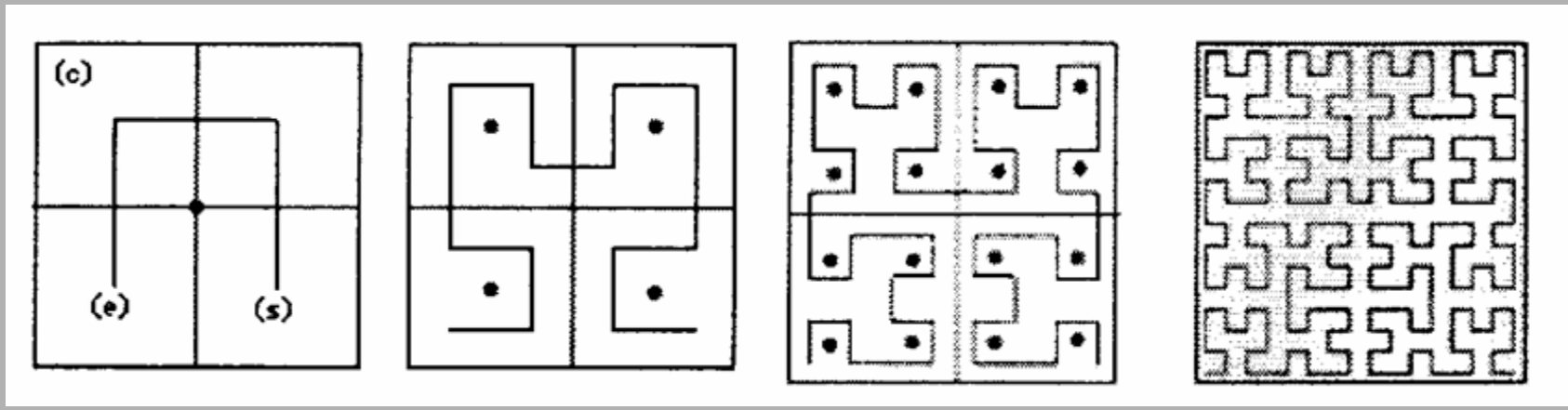
- *DNA data storage* advocates the use of bacterial DNA as the long-lasting high-density data storage.
- *DNA tag/antitag system* designs fixed-length short oligonucleotide tags for identifying biomolecules (e.g. cDNA).
- *DNA signature* is important for registering a copyright of engineered bacterial and viral genomes.

Software

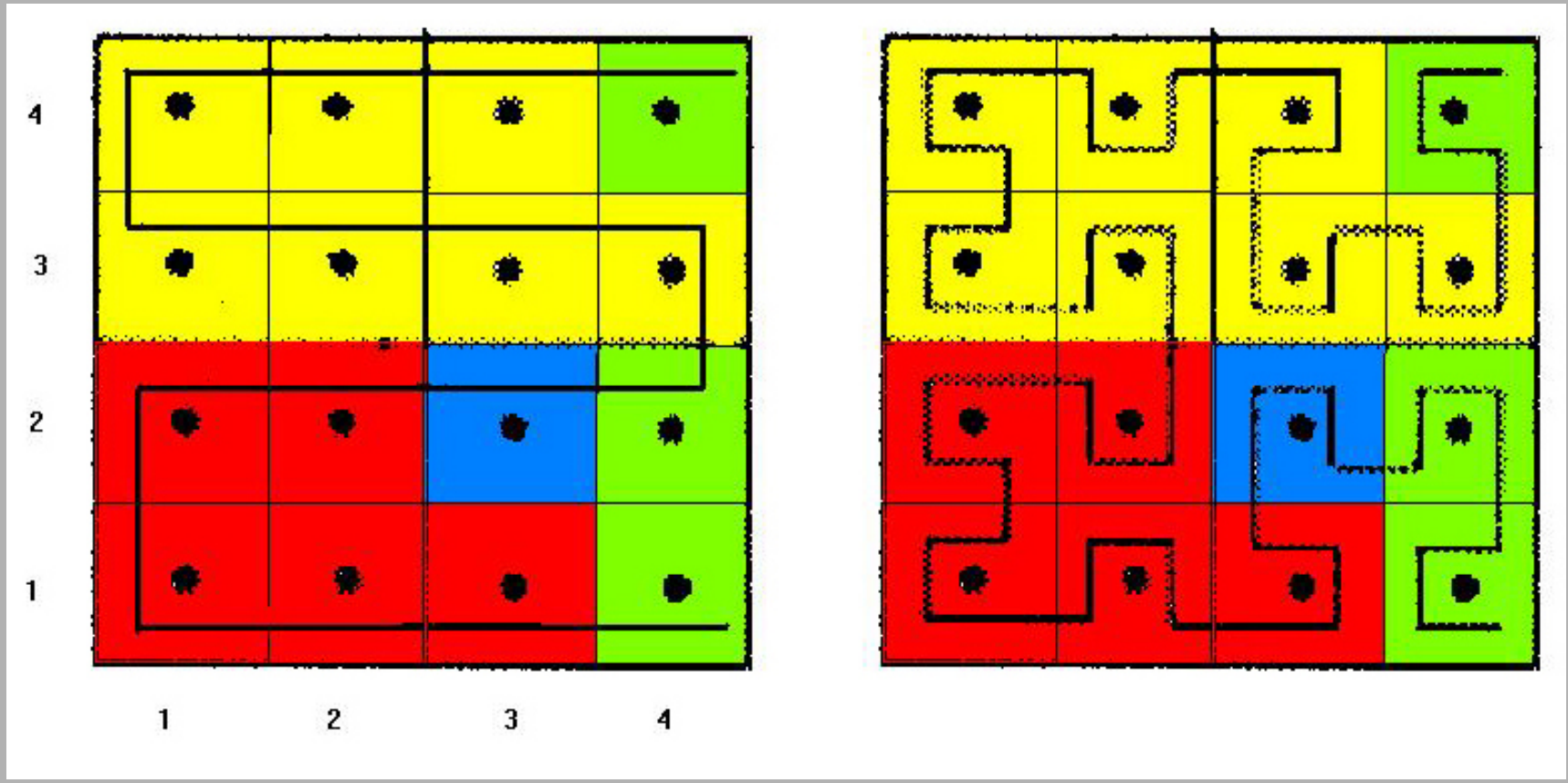


- Reads images pixel by pixel and converts the data into a sequence of alphabet of 4 letters {A, T, C, G}.
- Reads DNA sequences and converts the data into images.

Peano-Hilbert Space Filling Curve



A space-filling curve (SFC) is a continuous scan that traverses every pixel of an image exactly once. SFCs are attractive to many image-space algorithms which are based on the spatial coherence of nearby pixels.

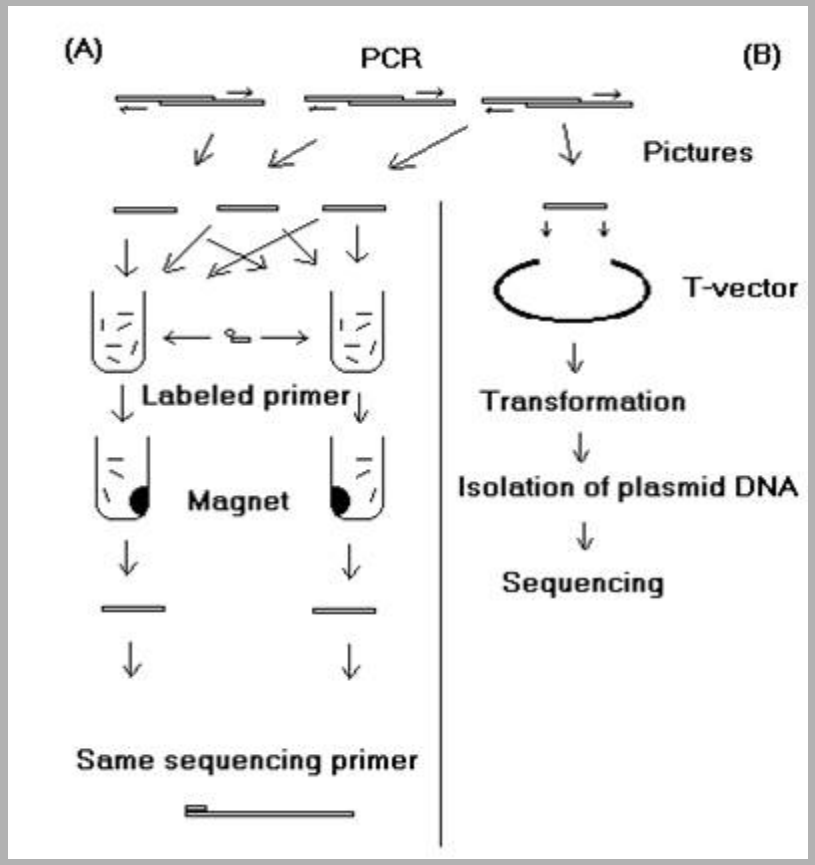


GRRRRRBGYYYYYYYG
GGBRRRRRYYYYYYYG
(G2B1R5Y7G1)

DNA code

- Coherent pixels (same colour) are shown as 4-number: A=0, T=1, C=2 and G=3.
- First digit in right shows the amount of 1s, second of 4s, 3rd of 16s etc.
- E.g.
  - AAA = 0 (0*16 + 0*4 + 0*1)
  - ATG = 7 (0*16 + 1*4 + 3*1)
  - TTG = 23 (1*16 + 1*4 + 3*1)

Stages of the Wet-laboratory Work



DNA memory prototype consists of four main steps: 1) encoding meaningful information as synthesised DNA sequences, 2) transforming the sequences to *E. coli*, 3) allowing the bacteria to grow and multiply, 4) extracting the information back from the bacteria.

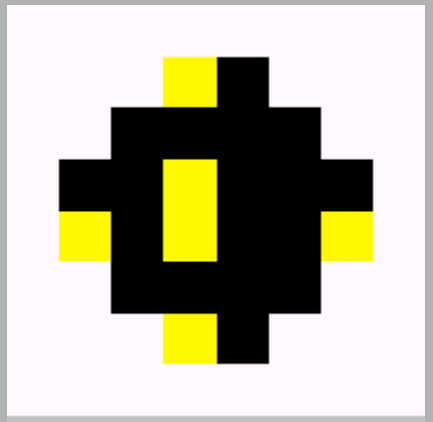
Results

```
                10        20        30        40        50        60        70        80        90        100
                ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
A7-6R           CANAATGTCCGGCCCATGGCGGCGCGGGATTCGTTTTCCTTCCTTCCTTTTTTTTTTTTTTTTTCATCTAATCAATTATTCATATAATCACTTACCCACTT
RaideMv         ------------------------------------TTCCTTCCTTCCTTTTTTTTTTTTTTTTTCATCTAATCAATTATTCATATAATCACTTACCCACTT

                110       120       130       140       150       160       170       180       190       200
                ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
A7-6R           AATCATATATTCAATTAATCATCAATCACTAGTGAATTCGCGGCCGCCTGCAGGTCGACCATATGGGAGAGCTCCCAACGCGTTGGATGCATAGCTTGAG
RaideMv         AATCATATATTCAATTAATCATC-----------------------------------------------------------------------------

                210       220       230       240       250       260       270       280       290       300
                ....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
A7-6R           TATTCTATAGTGTCACCTAAATAGCNTGGCGTAATCATGGTCATAGCTGTTTCCTGTGTGAAATTGTTATCCGCTCACAATTCCACACAACATACGAGCC
RaideMv         -----------------------------------------------------------------------------------------------

                310       320       330
                ....|....|....|....|....|....|....|
A7-6R           GGAAGCATAAAGTGTAAAGCCTGGGGTGCCTAATG
RaideMv         -----------------------------------
```



Images that had been stored into plasmid DNA stayed unchanged.

Conclusion:

With a careful coding plan and arrangements, important information can be encoded as a synthesised DNA strand and safely stored in a living host.
But there are no known efficient algorithms for design of DNA word sets

Future:

Better coding: Software for sequence design to avoid mishybridisation