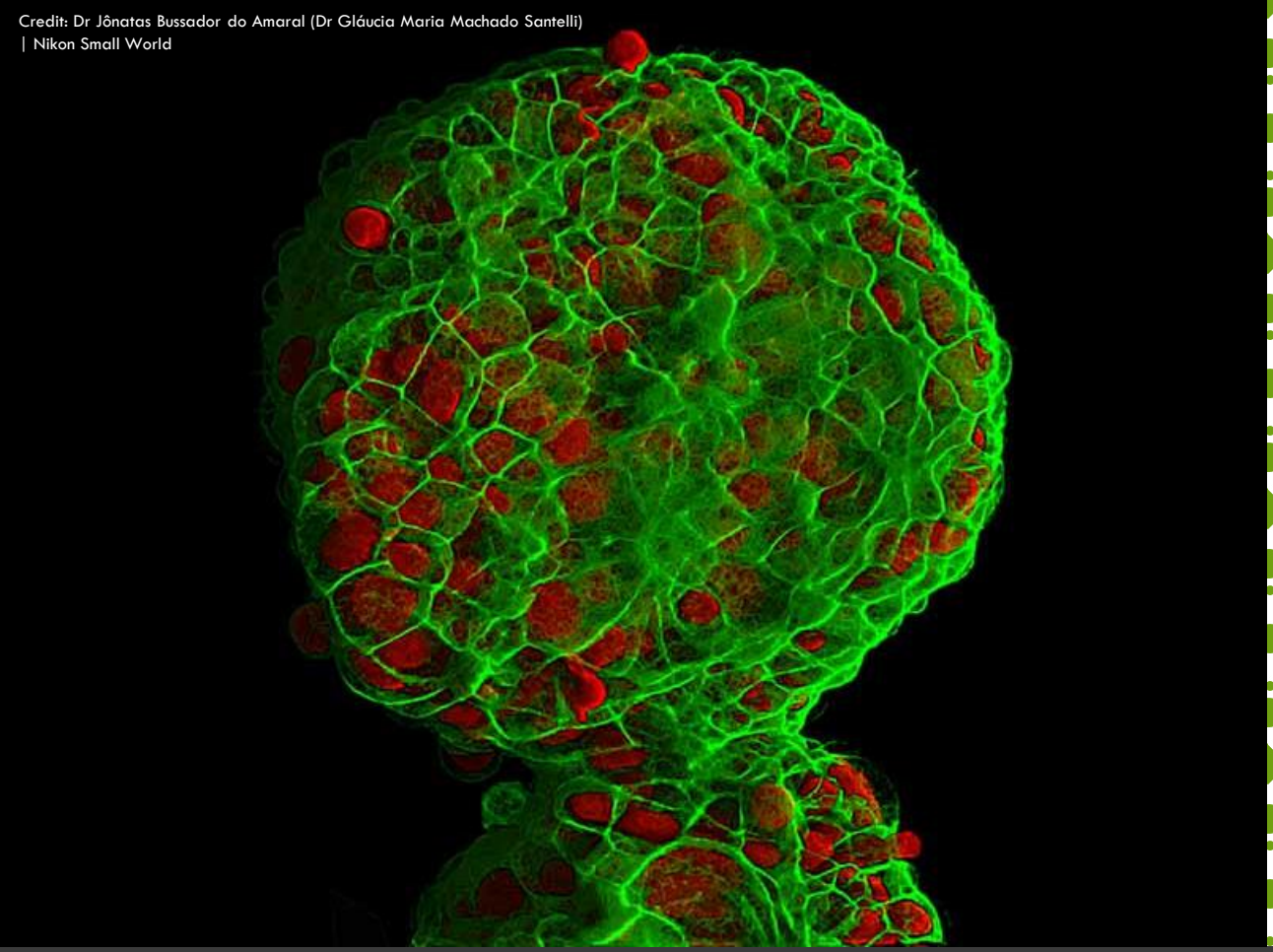
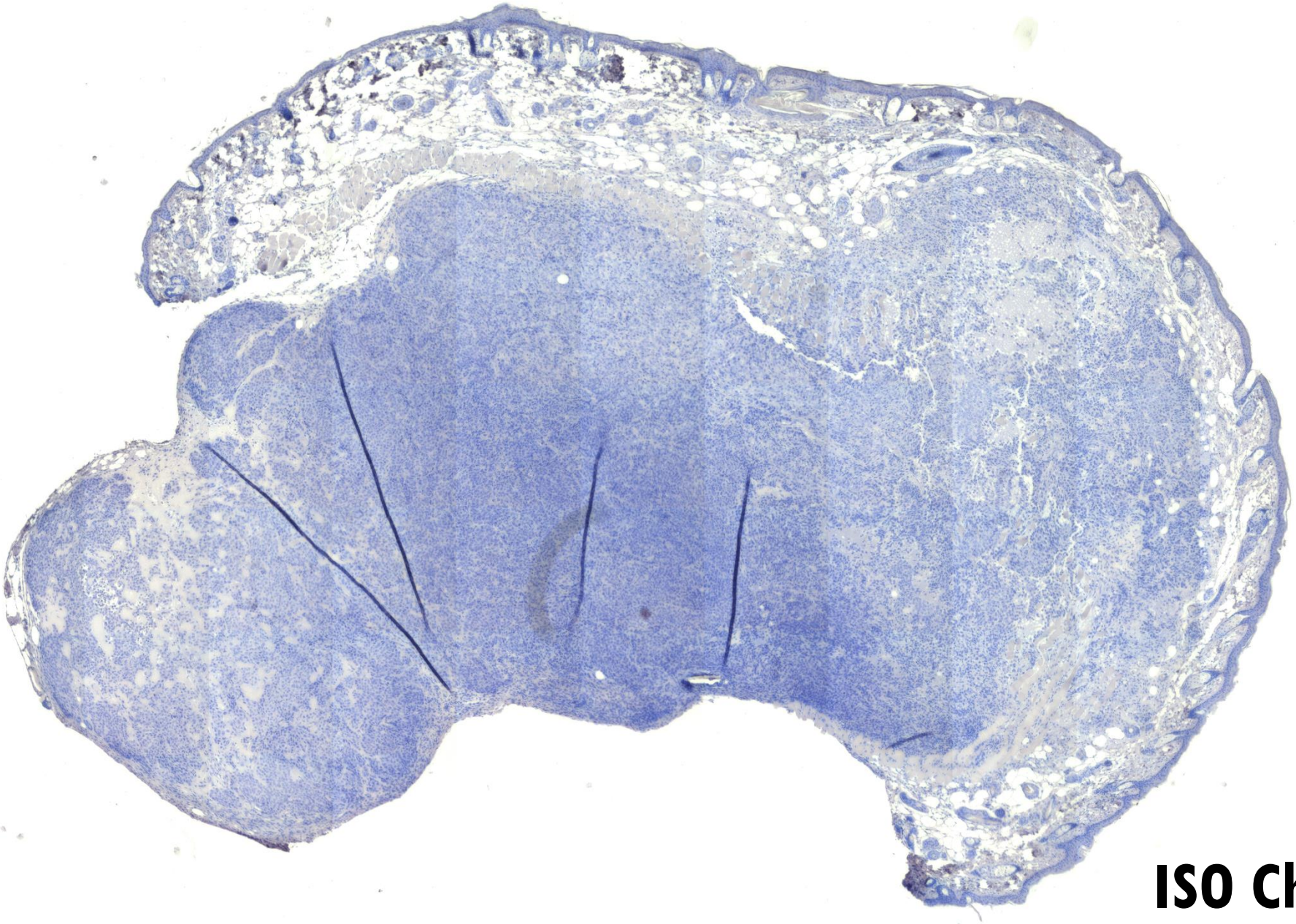
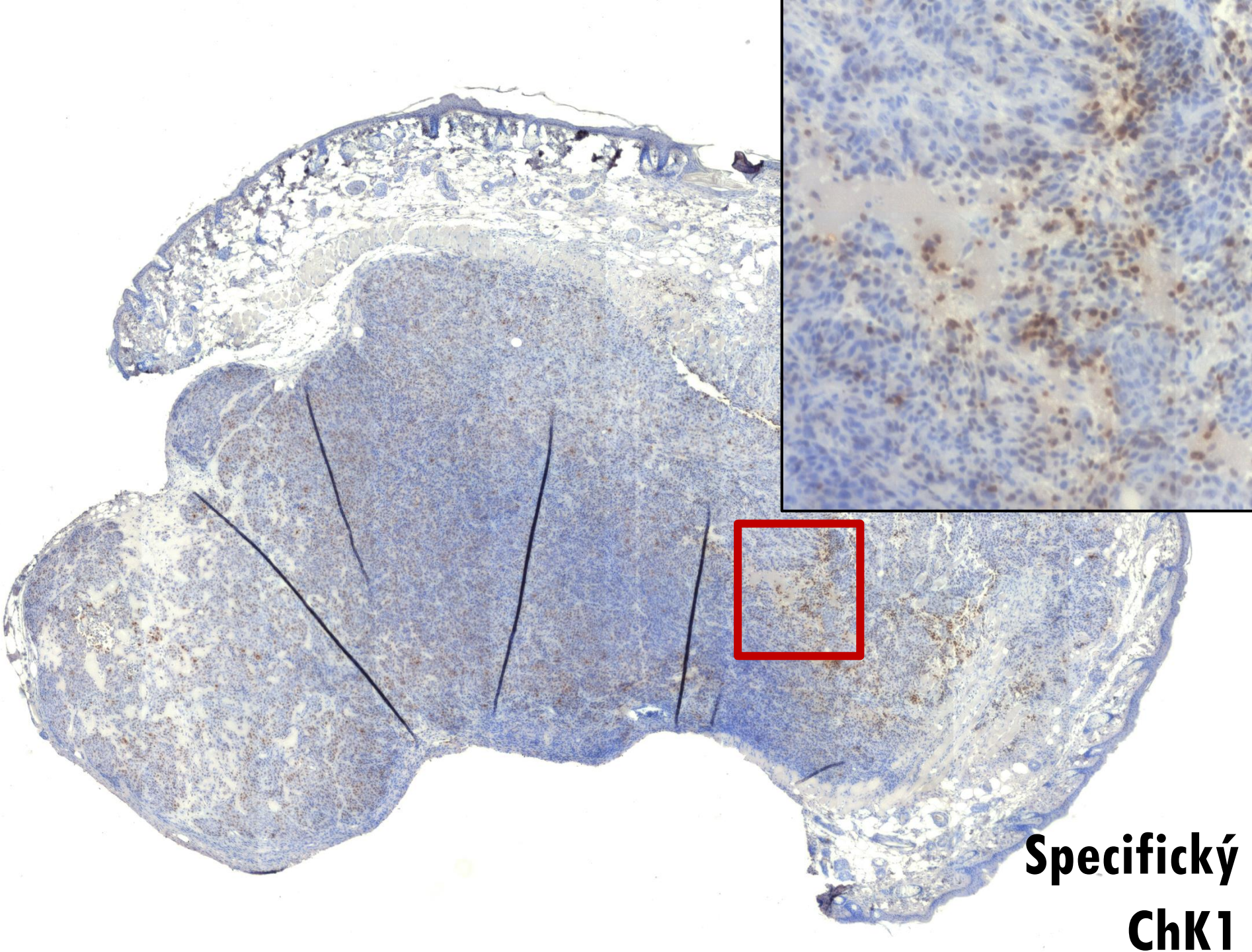


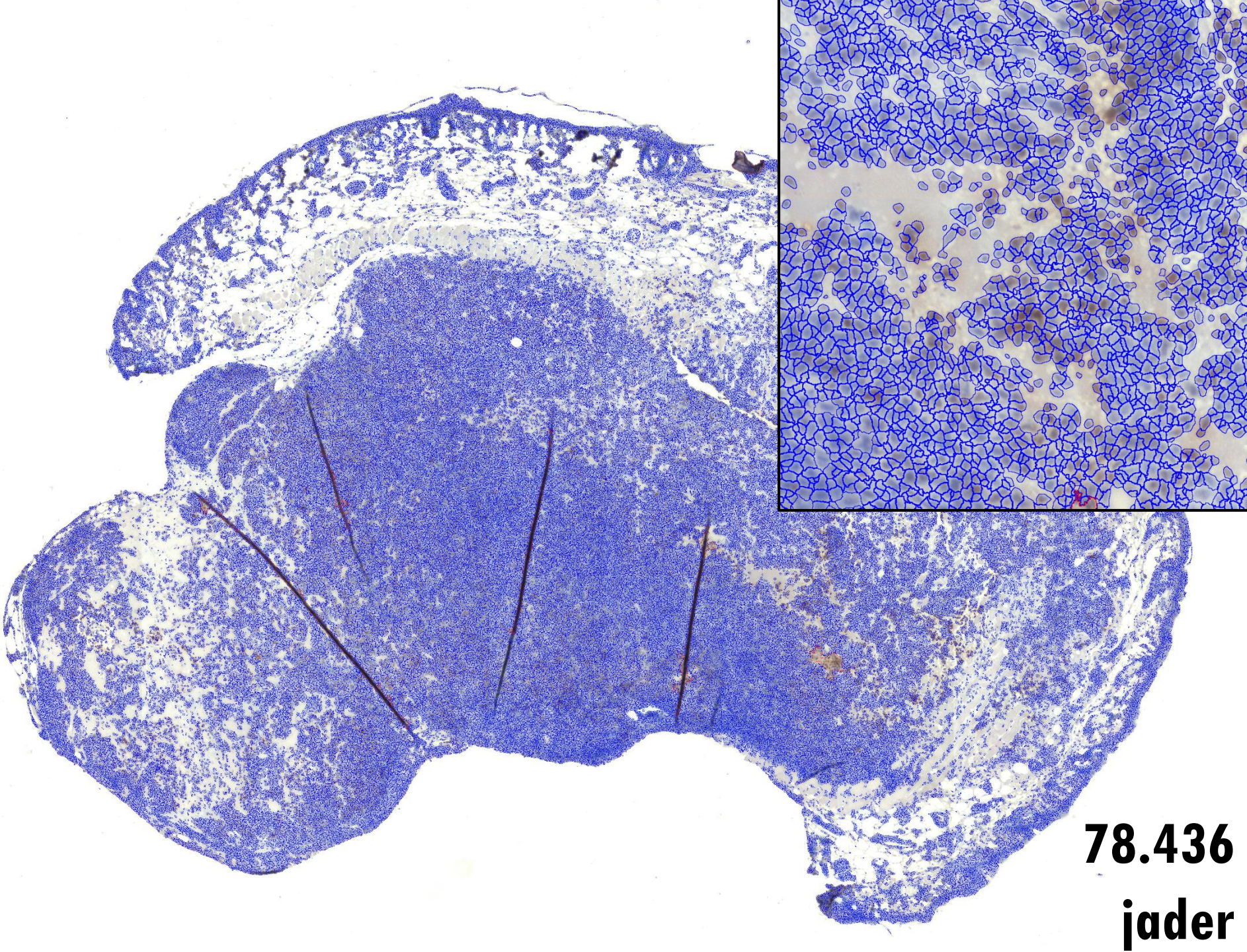
ZÁKLADNÍ PRINCIPY ANALÝZY OBRAZU

Příklady analýzy obrazu

Radek Fedr

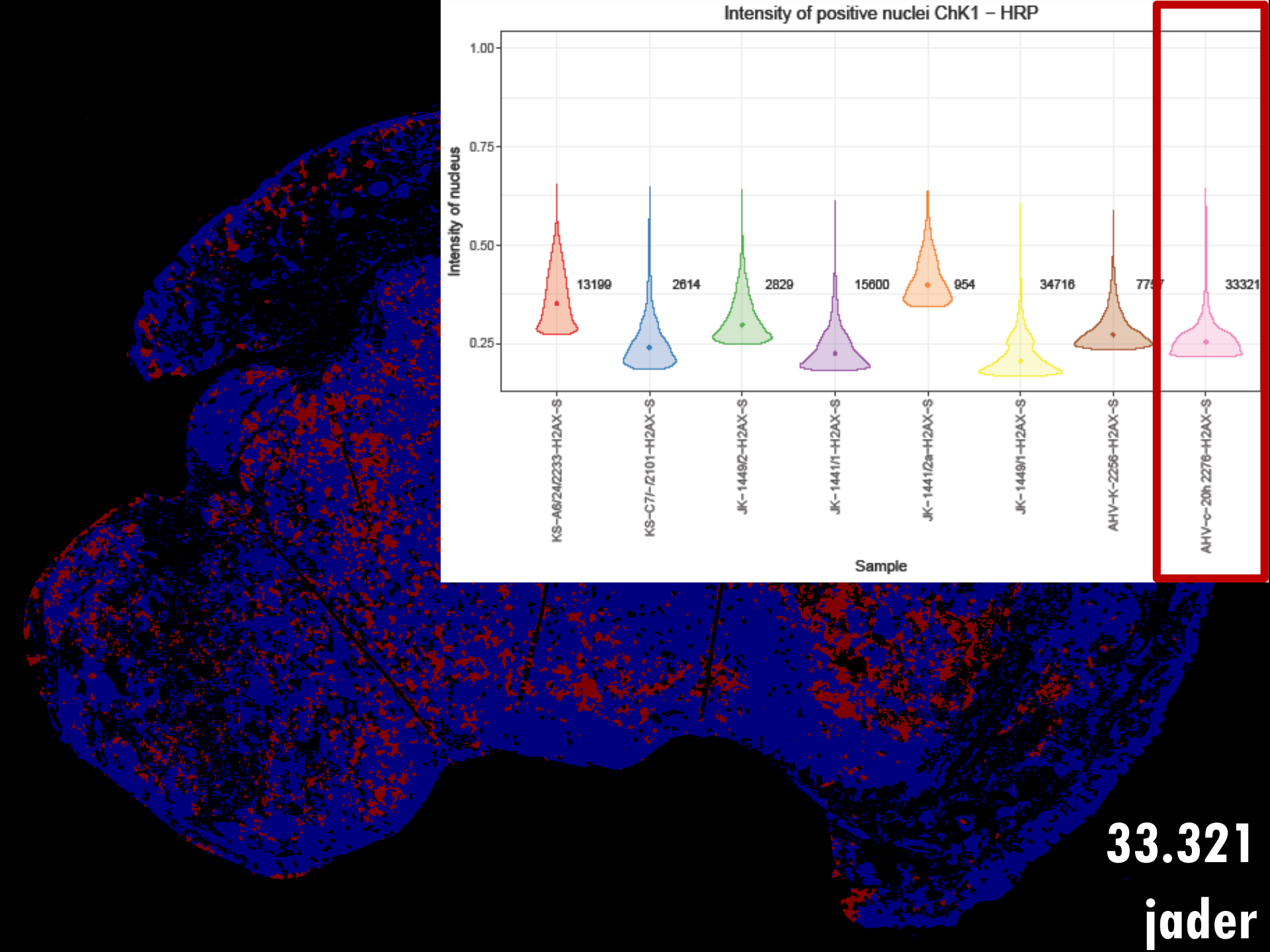

ISO ChK1


Specifický
ChK1



78.436

jader


Intensity of positive nuclei ChK1 – HRP
Intensity of nucleus
1.00
0.75
0.50
0.25
13199
2614
2829
15600
954
34716
33321
KS–A6/24/2233–H2AX–S
KS–C7/–/2101–H2AX–S
JK–1449/2–H2AX–S
JK–1441/1–H2AX–S
JK–1441/2a–H2AX–S
JK–1449/1–H2AX–S
AHV–K–2256–H2AX–S
AHV–c–20h 2276–H2AX–S
Sample
33.321
jader

ANALÝZA TKÁNÍ

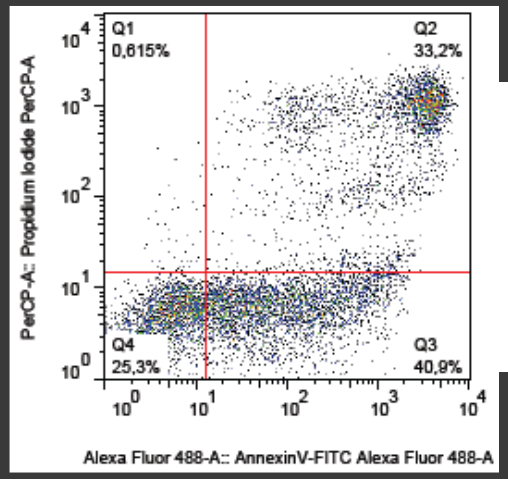
- 16 tkáňových řezů (8 ISO + 8 specifické)
- 23,3 GB dat obrazů
- 200 zorných polí/řez
- 5 684 588 jader
- 1,5h analýza obrazů
- 36 parametrů/jádro
- 40 GB dat celkem

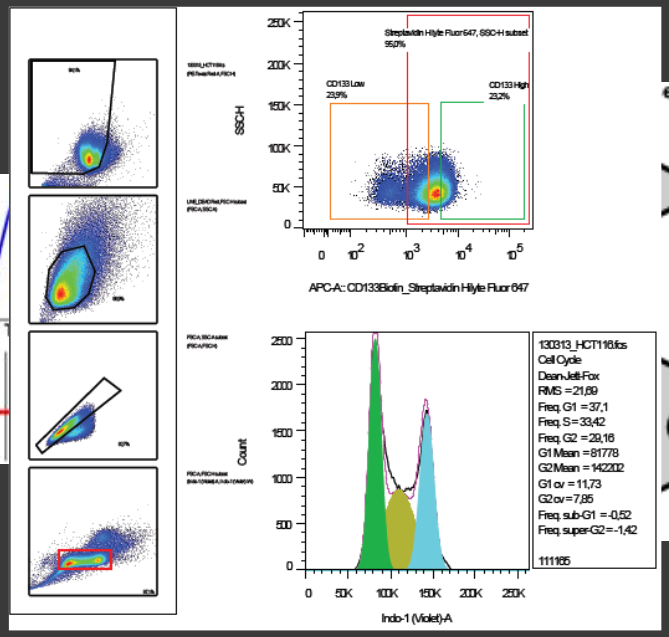
CellProfiler
cell image analysis software

RStudio®

PRŮTOKOVÁ CYTOMETRIE

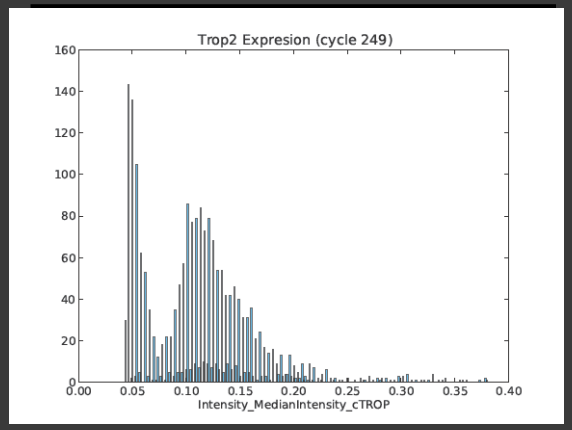
- Pulz
- Intenzita - částice
- Distribuce
- Histogram/Bodový graf
- End-point

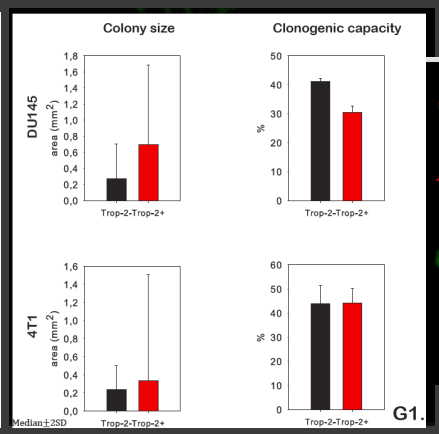


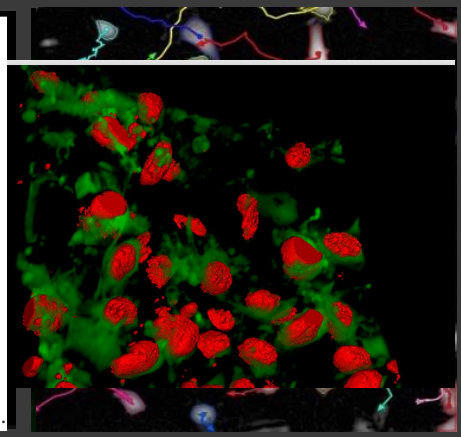


OBRAZOVÁ CYTOMETRIE

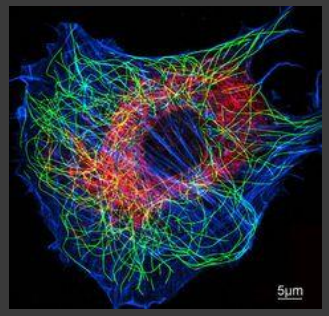
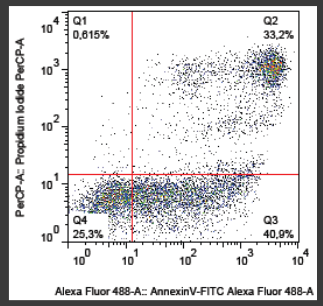
- **Pixel**
- Intenzita - pixel
- Distribuce
- Obraz, Projekce
- Graf, Model
- Tracking/Sledování





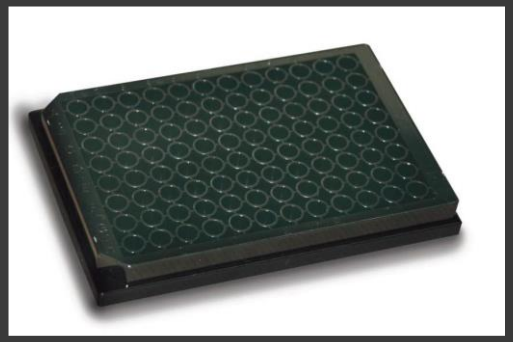


SROVNÁNÍ

	Mikroskopie	Průtoková cytometrie
Ukázka		
Vzorek	2D, 3D	Suspenze
Rozlišení	100nm	1částice/1µm
Fluorescenční parametry	1-5	10+
Rychlost	100 buněk/s	10000 buněk/s
Data	100GB	100MB
Kvantifikace	Přesná	Přesná
Počet buněk	10^1-10^6	10^4-10^7

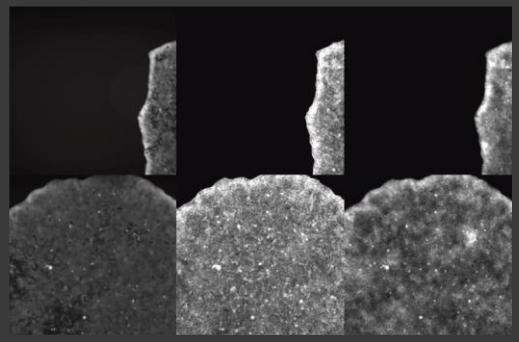
POSTUP

Příprava vzorku

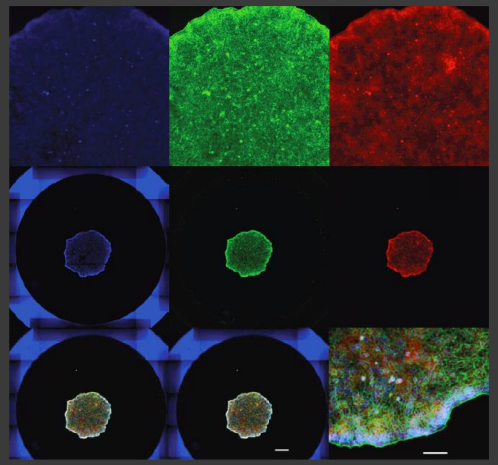


Snímání

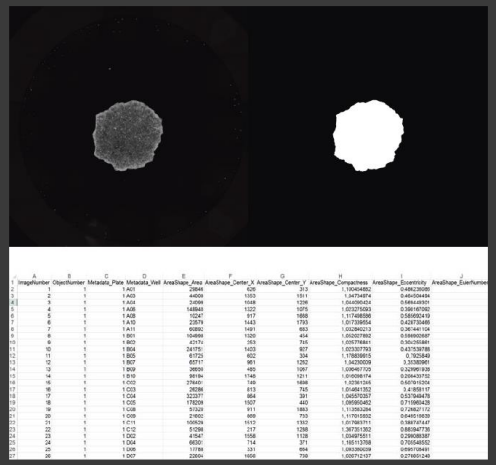
Uložení dat



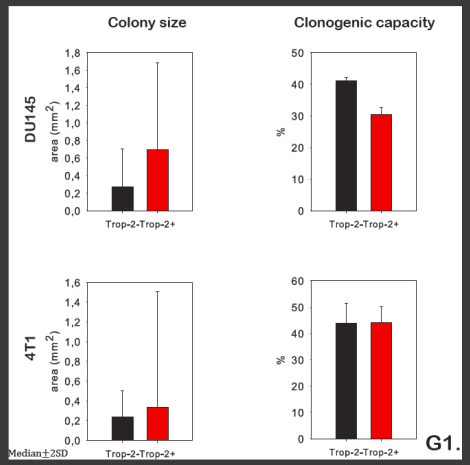
Zpracování



Analýza



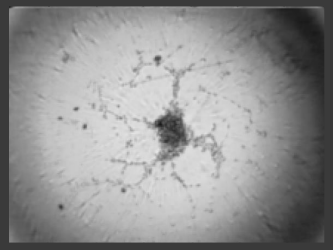
Vyhodnocení dat

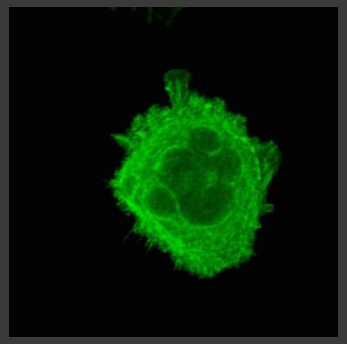


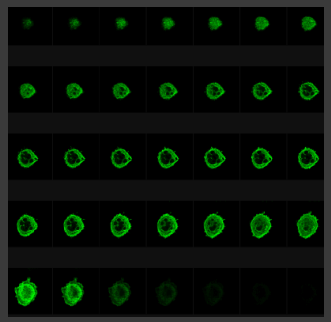
PŘÍPRAVA A SNÍMÁNÍ

Experiment

- živé
- fixované
- 2D
- 3D

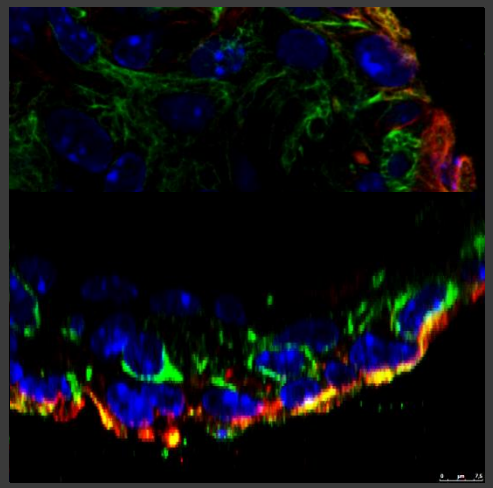




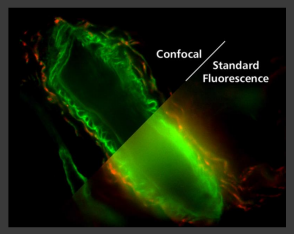


Vzorek

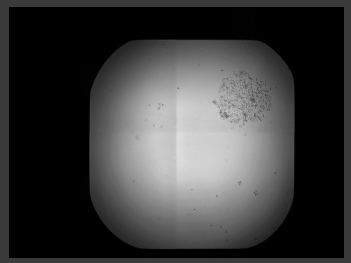
- suspenze
- monovrstvy
- kokultivace
- tkáň
- sferoidy
- organoidy



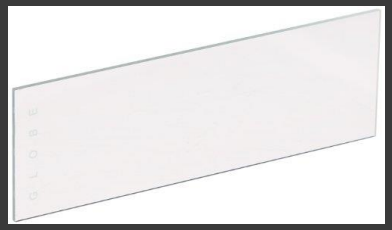
Mikroskopie

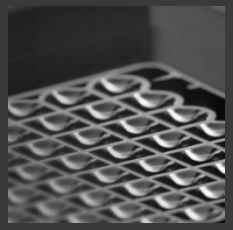


- průchozí světlo
- fázový kontrast
- fluorescence
- konfokální
- holografická
- elektronová



PŘÍPRAVA A SNÍMÁNÍ



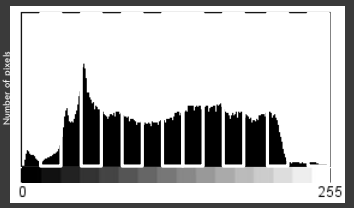


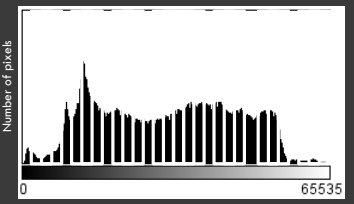
Plast

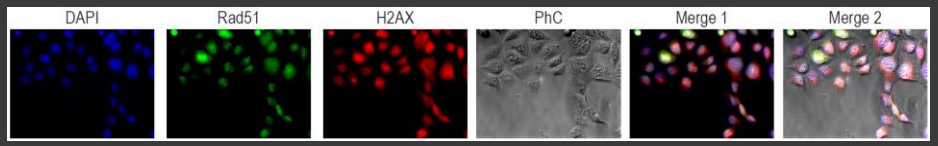
- podložní sklo
- ztenčené dno
- více-jamkové desky

Rozlišení

- objektiv
- bitová hloubka
- počet barev







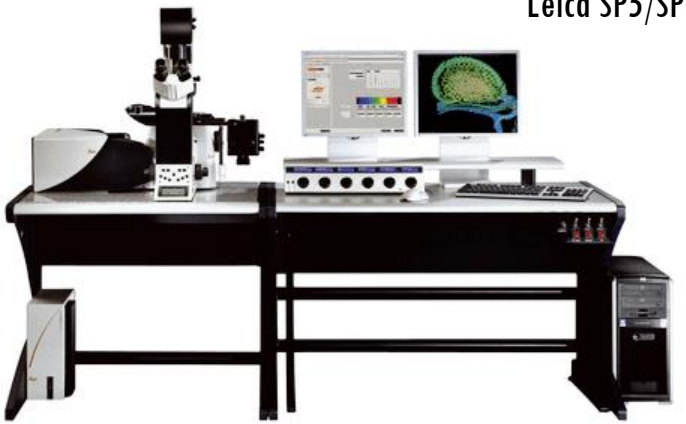
SNÍMÁNÍ

- Příprava
- Automatické
- Zatmavení
- Popis
- Vyhodnocení

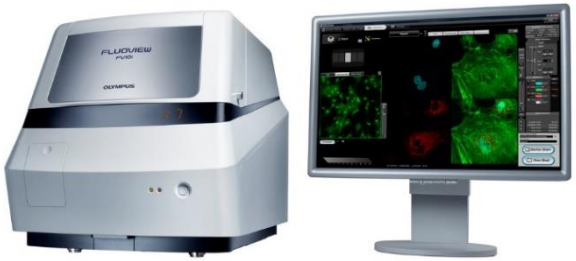
vzorku

MIKROSKOP

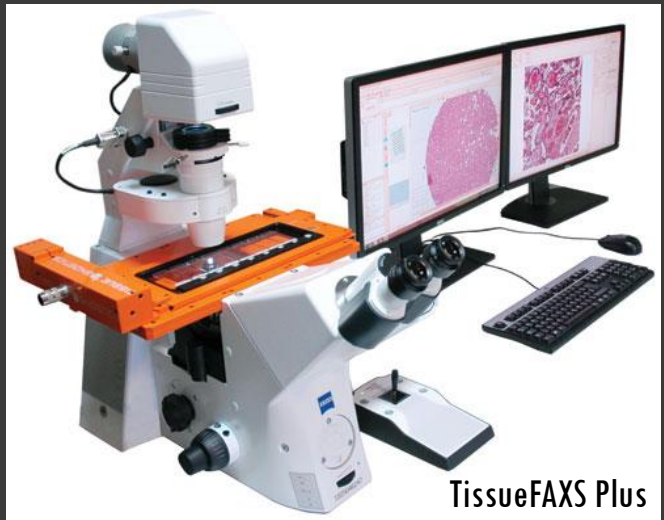
Leica SP5/SP8



Olympus/Leica

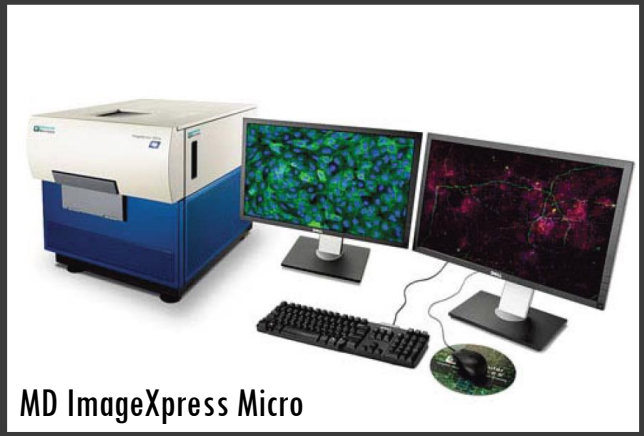


Olympus FV10i



TissueFAXS Plus

Olympus IX70

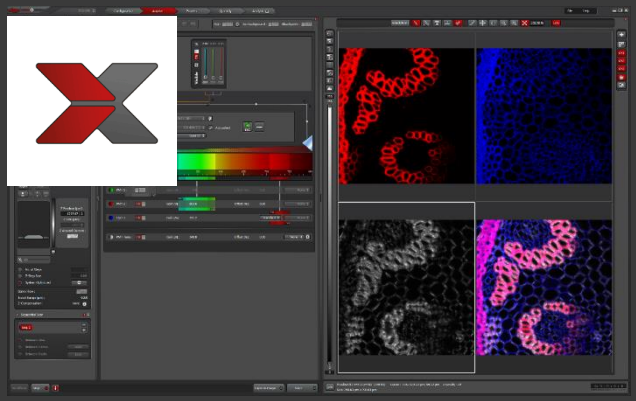


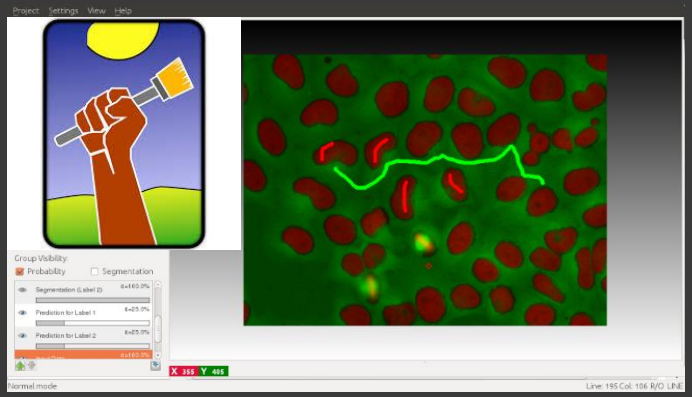
MD ImageXpress Micro

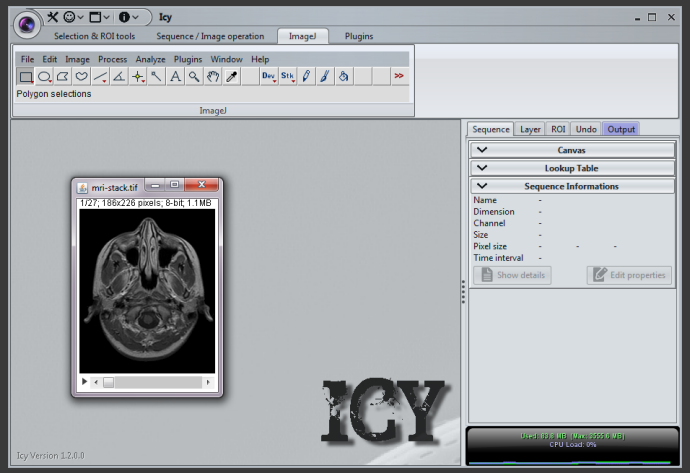
SOFTWARE

CellProfiler
cell image analysis software

R Studio®

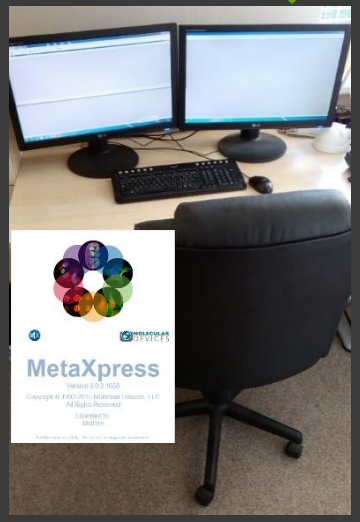






DATA

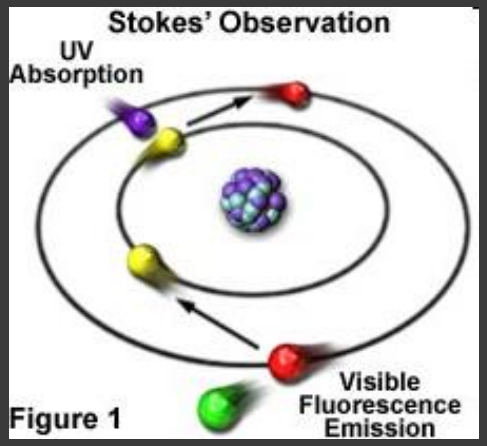
CellProfiler™
cell image analysis software

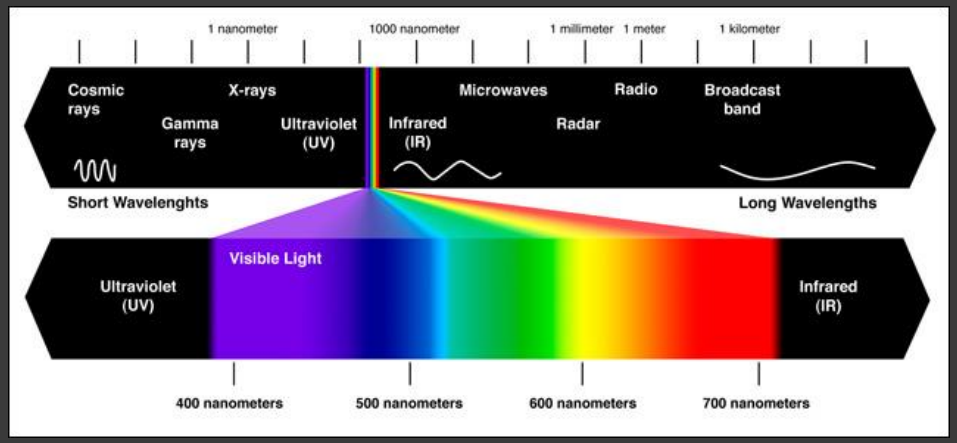


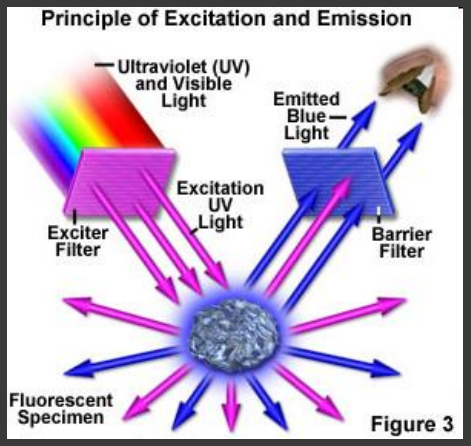
“THE FIRST RULE OF ANY TECHNOLOGY USED IN A BUSINESS IS THAT AUTOMATION APPLIED TO AN EFFICIENT OPERATION WILL MAGNIFY THE EFFICIENCY. THE SECOND IS THAT AUTOMATION APPLIED TO AN INEFFICIENT OPERATION WILL MAGNIFY THE INEFFICIENCY.”

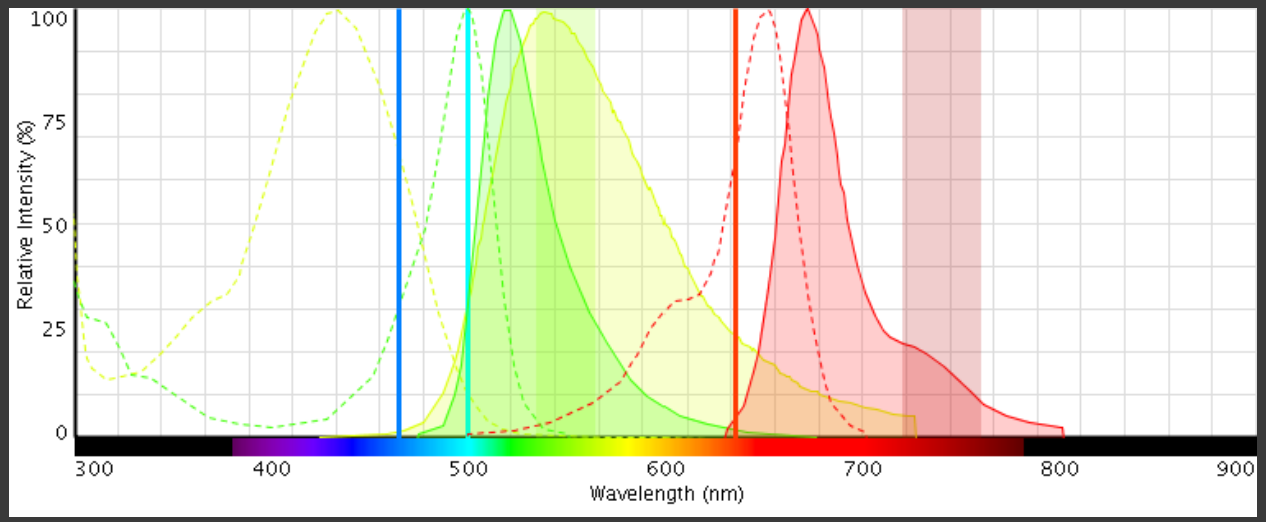
Bill Gates

FLUORESCENCE

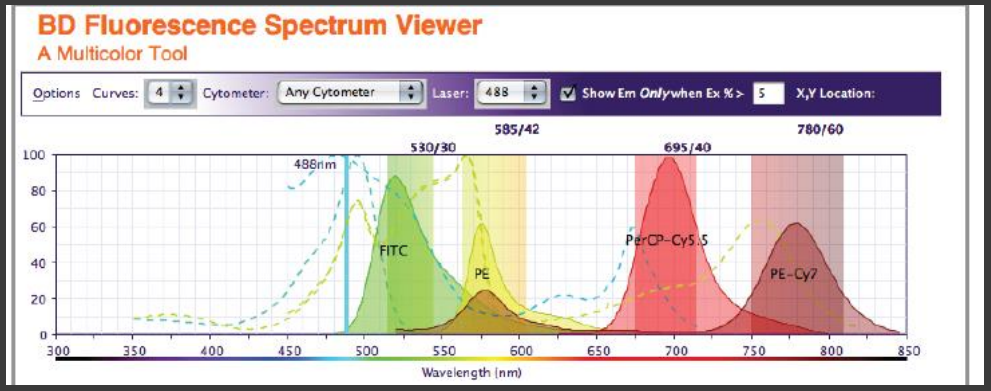


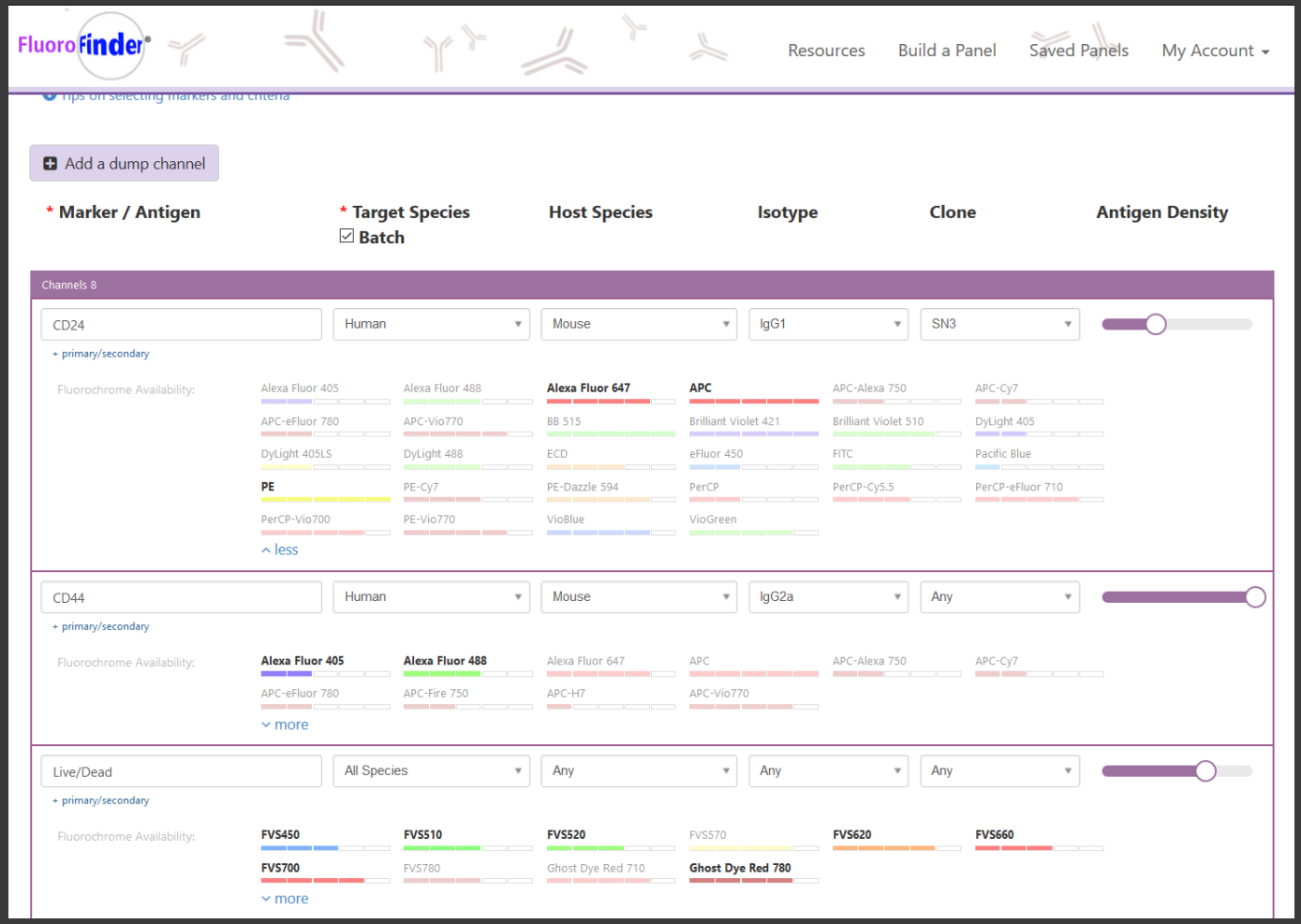






FLUOROCHROM





- Síla fluorescence fluorochromů není stejná!
- spectraviewer
- www.fluorofinder.com

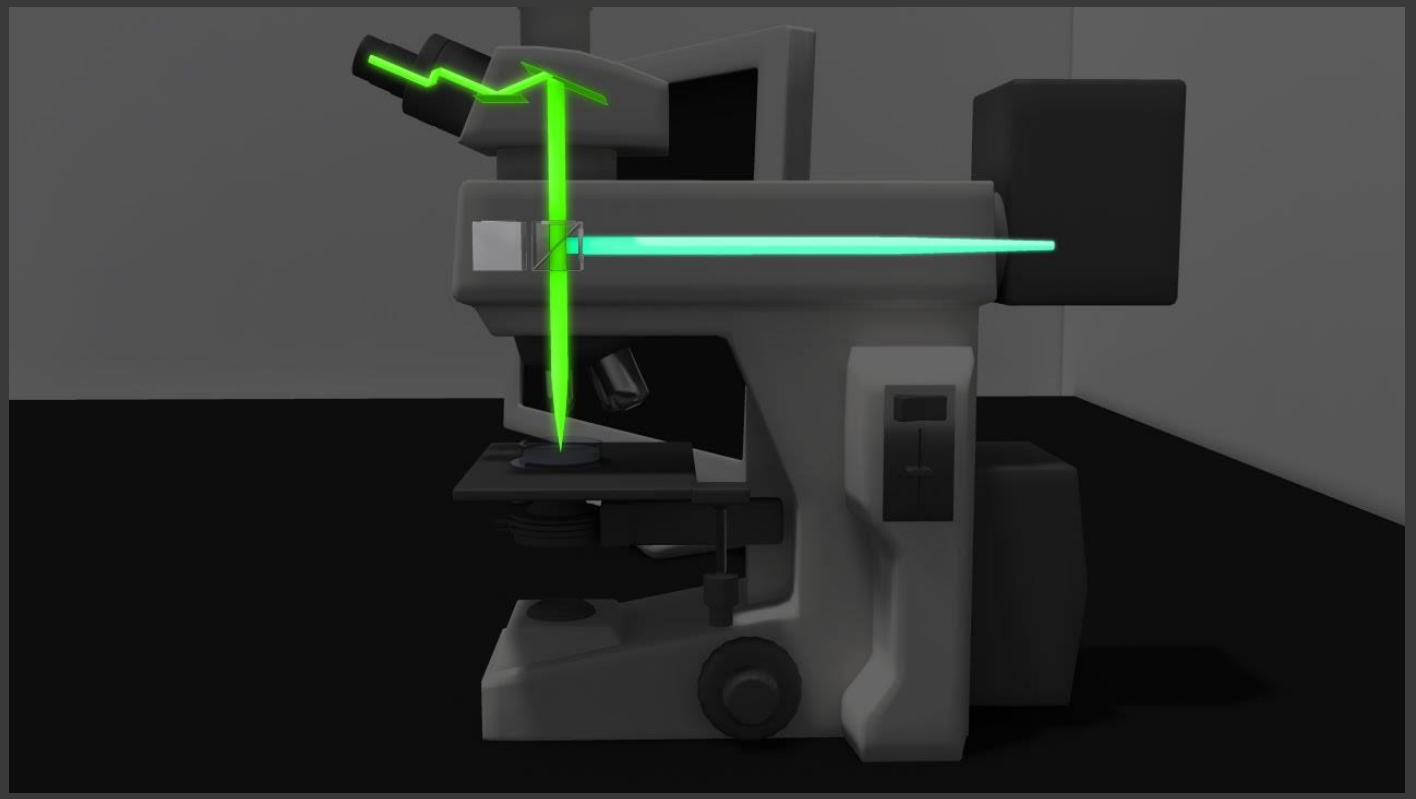
FLUOROCHROM

- Různý **JAS** fluorochromů
- Různá **stabilita/životnost** fluorochromů
- Nejméně exprimovaný protein = nejsilnější fluorochrom
- Silně exprimovaný protein = slabší fluorochrom

- Historicky 488nm argonový laser – FITC vs. Alexa Fluor 488 etc.

SNÍMÁNÍ OBRAZU

- Úkolem je **zachytit zvětšený obraz reality**
- Čip / PMT / HyD detektor

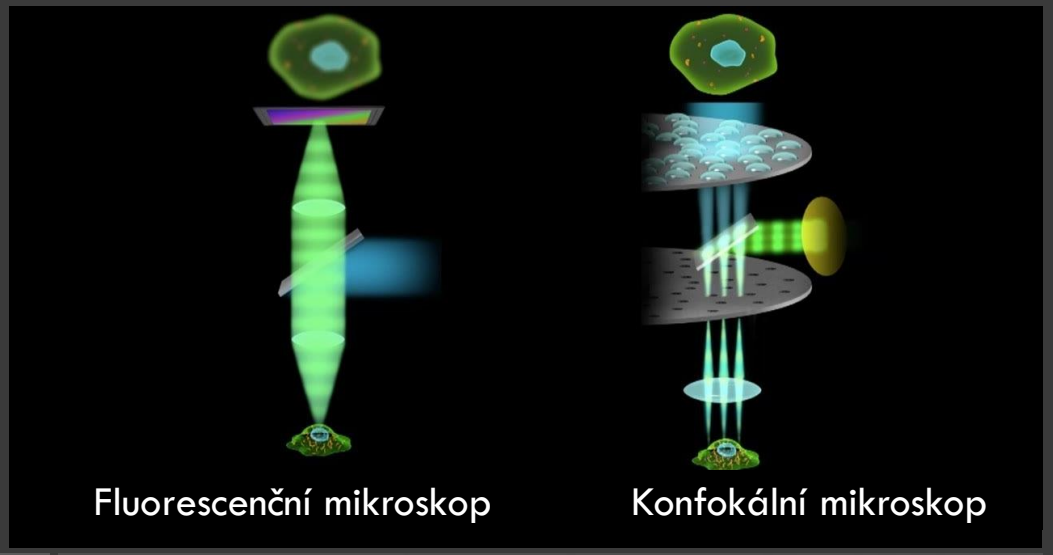


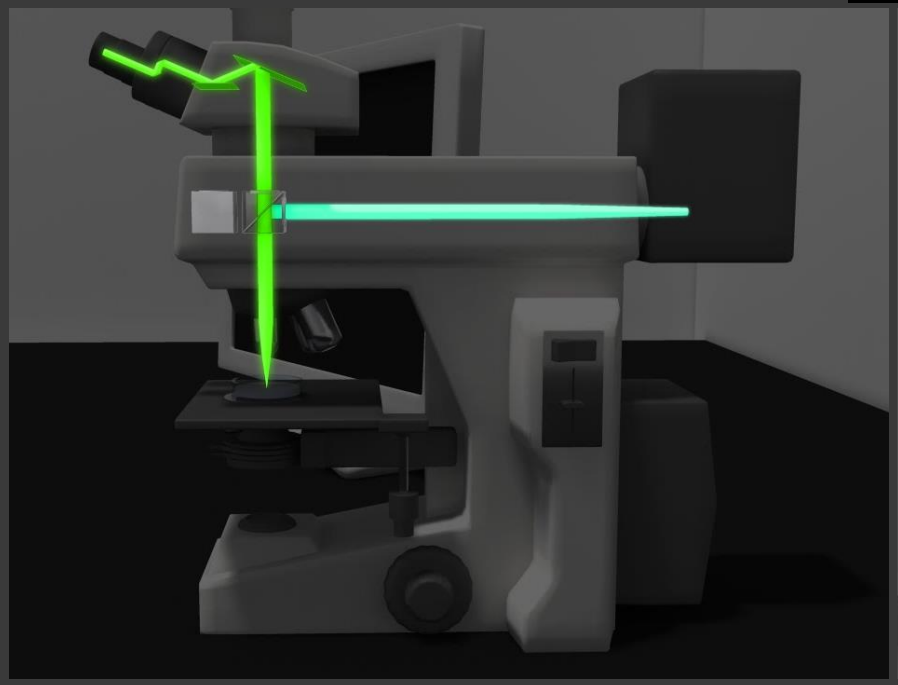
SNÍMÁNÍ OBRAZU

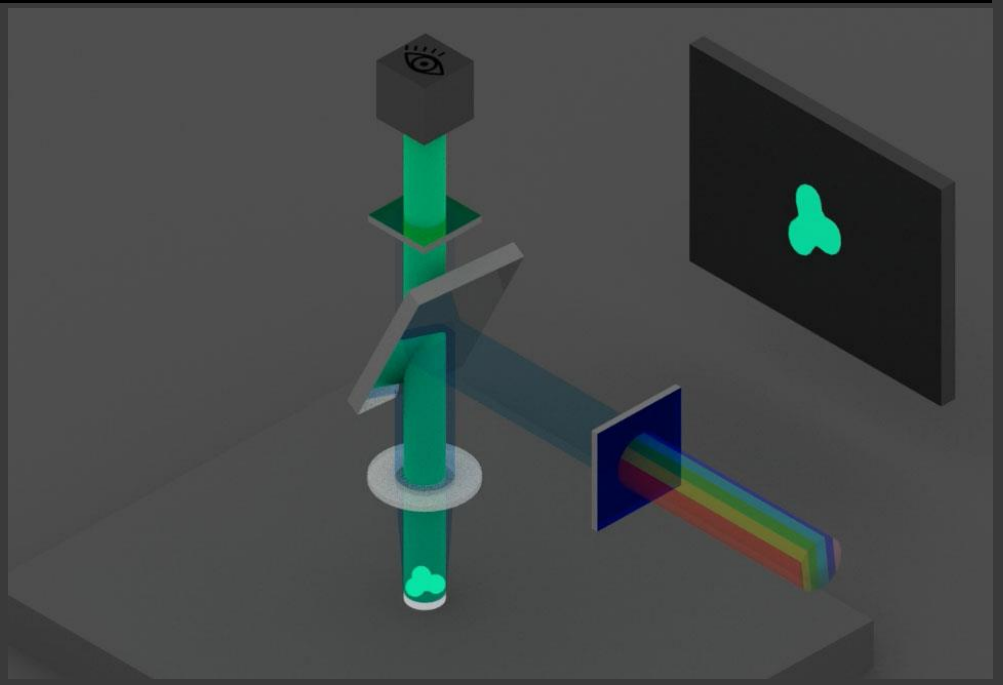
- Fluorescenční mikroskop

vs.

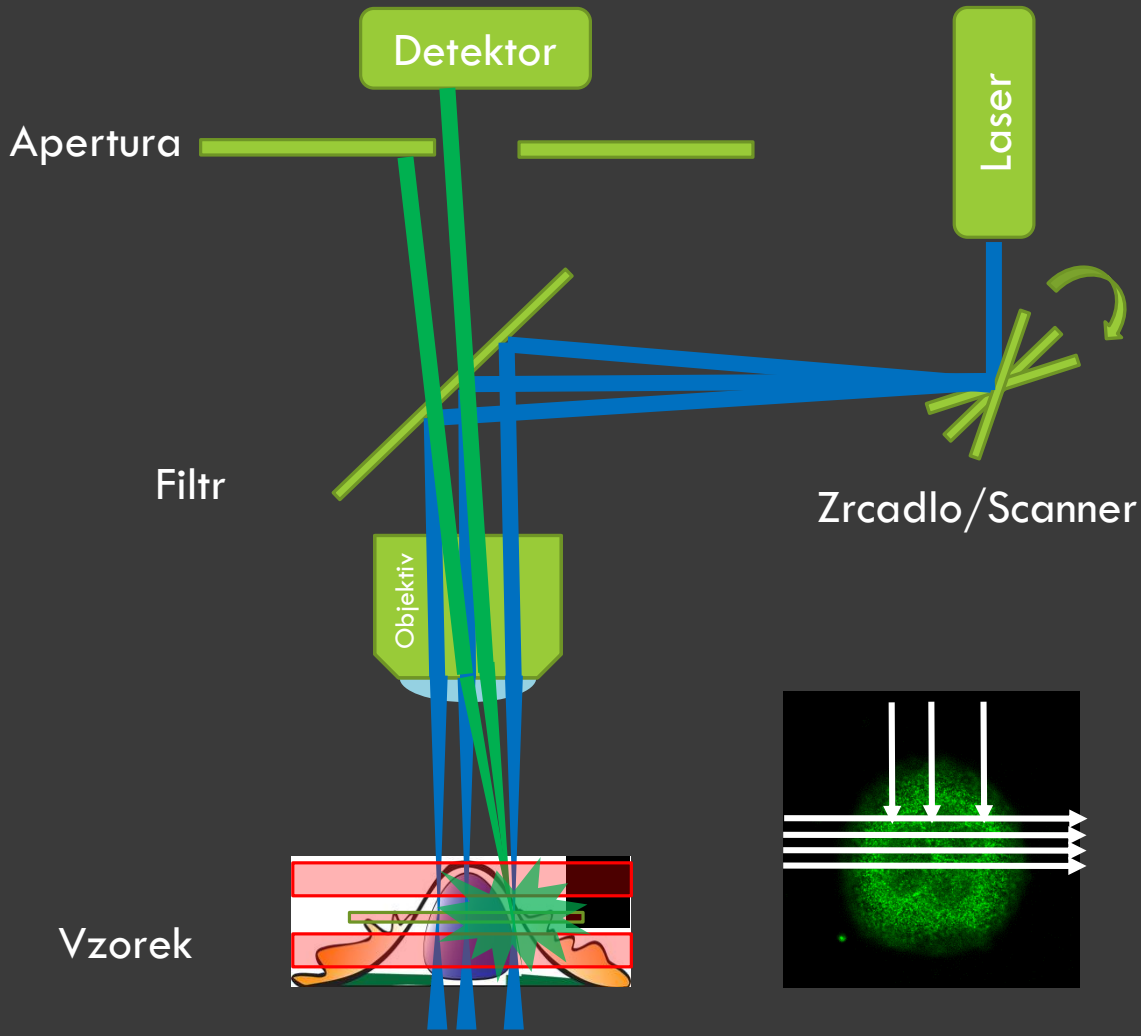
- Konfokální mikroskop



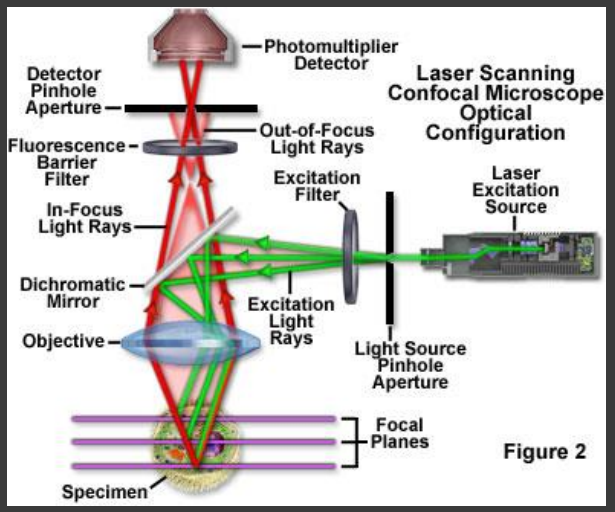




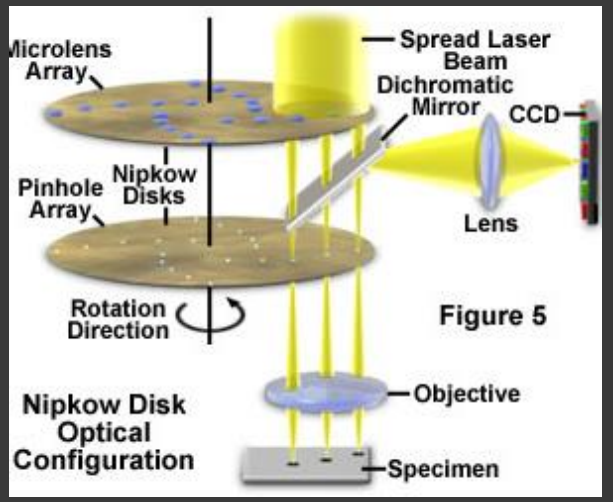
SNÍMÁNÍ OBRAZU



Laser scanning

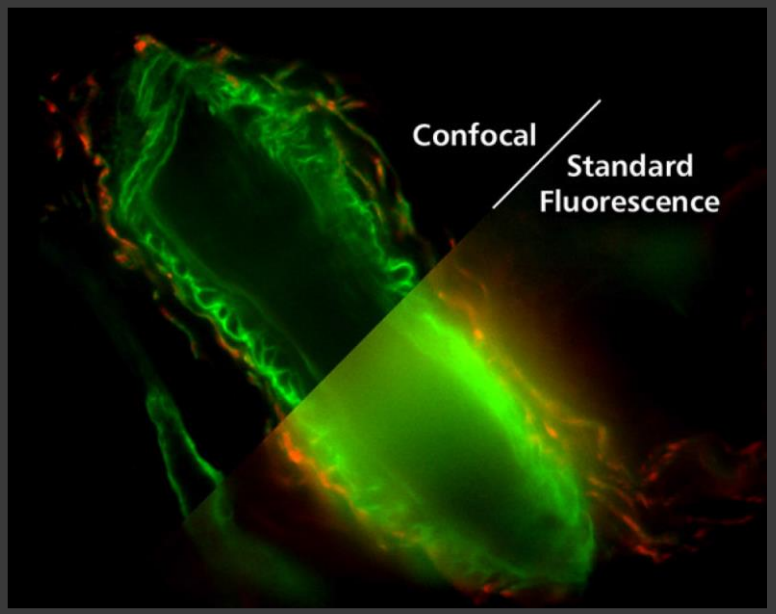


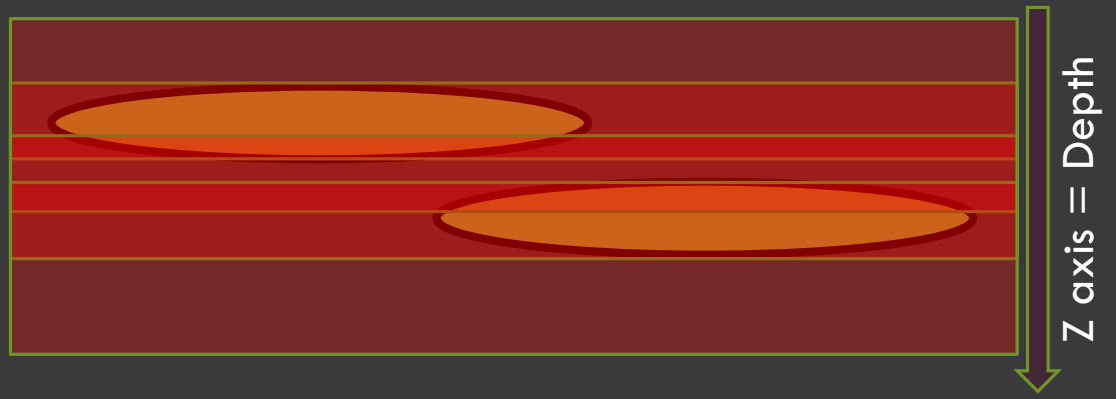
Spinning disc

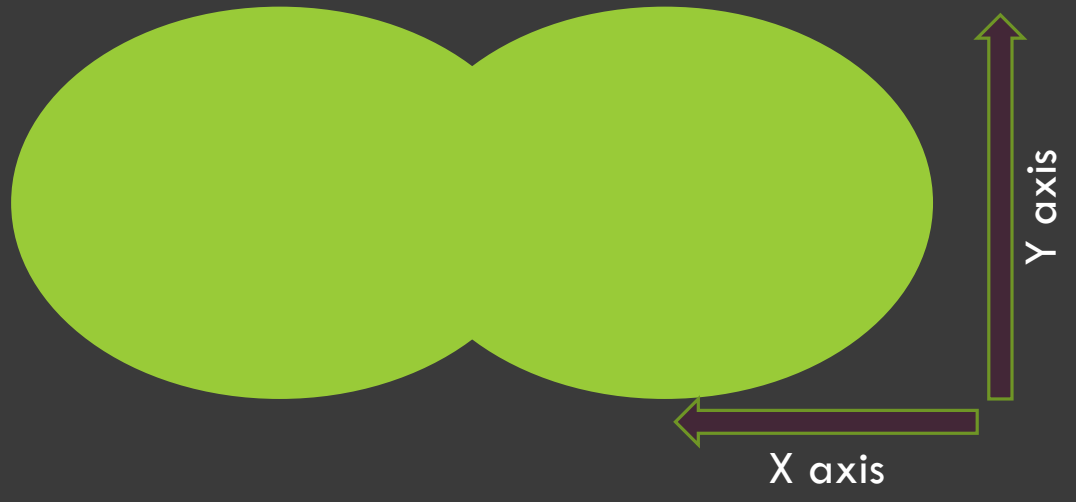


KONFOKÁLNÍ MIKROSKOP

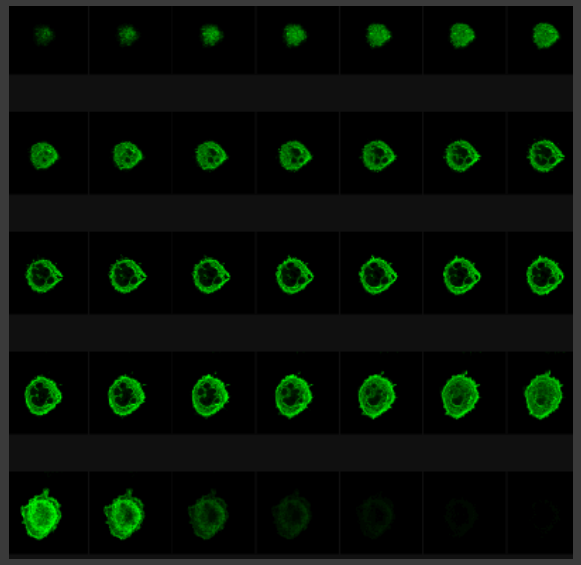
KONFOKÁLNÍ VS. FLUORESCENČNÍ MIKROSKOP

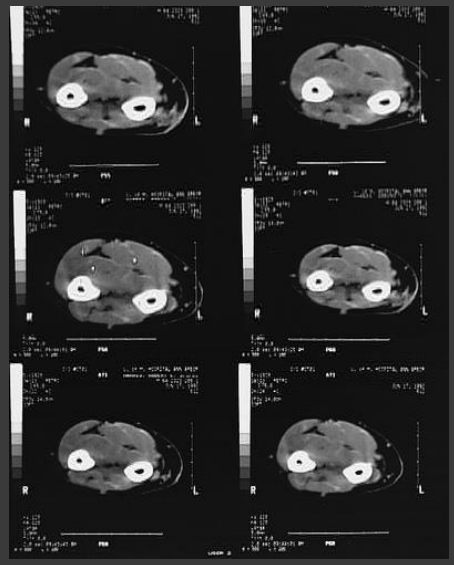


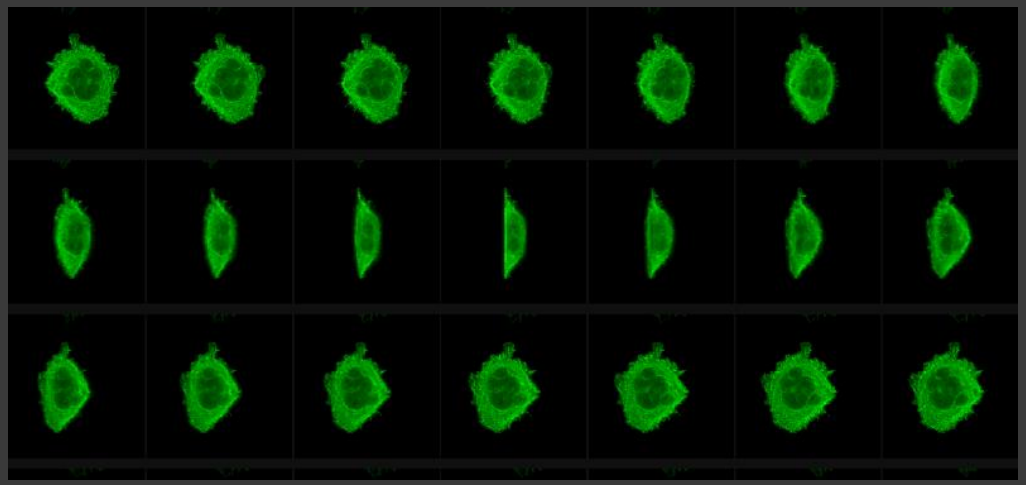




KONFOKÁLNÍ VS. FLUORESCENČNÍ MIKROSKOP







LIDSKÉ OKO

- 400-700 nm (380-760)

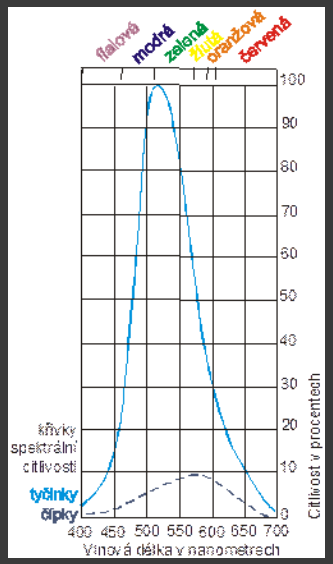
Tyčinky (černobílé)

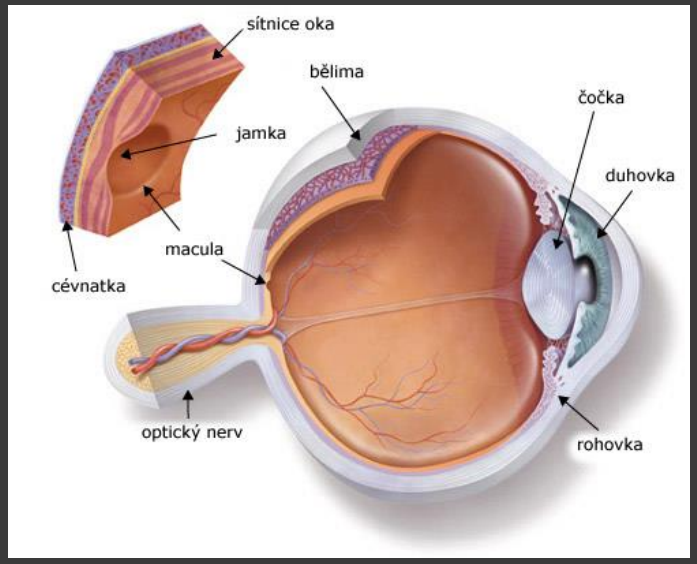
- 500nm, 20x více než čípků

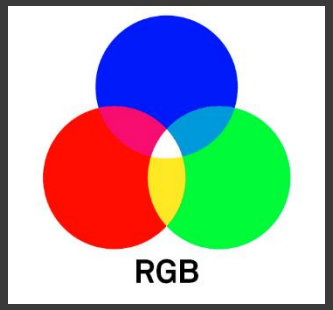
Čípky (R,G,B) (barevné)

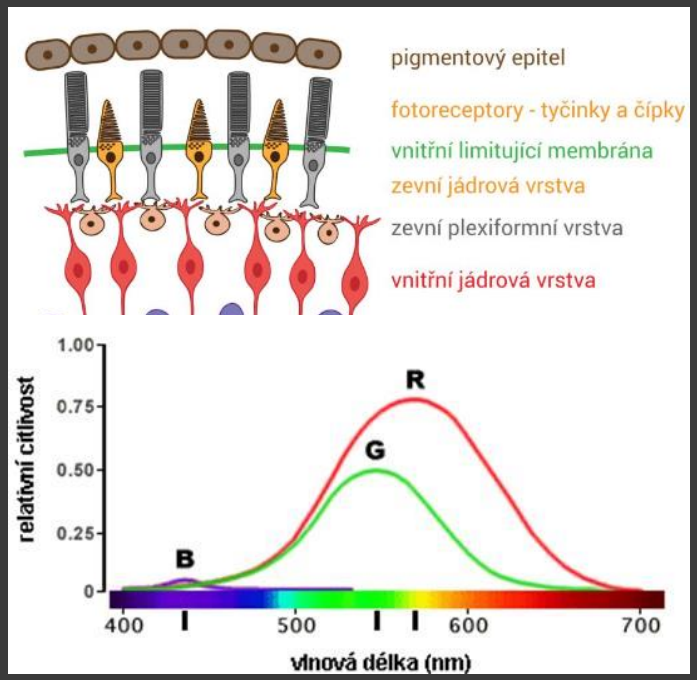
- 400-500nm Modrá – 4% 440 nm
- 500nm-600nm Zelená - 32% 540nm
- 600-700nm Červená – 64% 570 nm

- Rozlišení 0,1-0,15mm, 25 cm
- 500 stupňů šedi, 10 milionů barev
- Adaptace na tmu 40 min
- 25snímků/s pohyb, zaostření 50 věcí/s, otisk prstu 40 parametrů – duhovka 256 parametrů



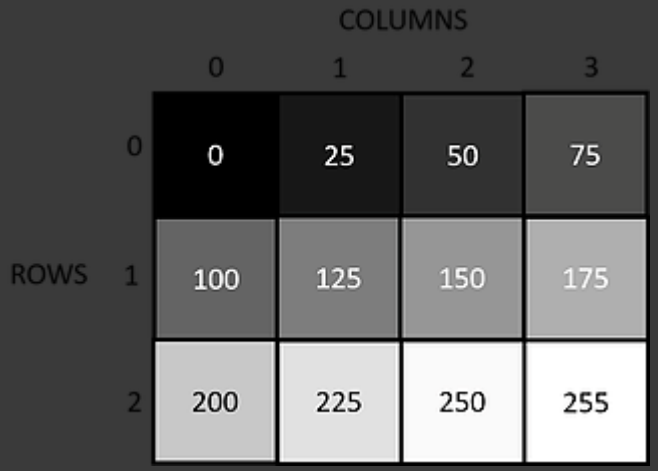


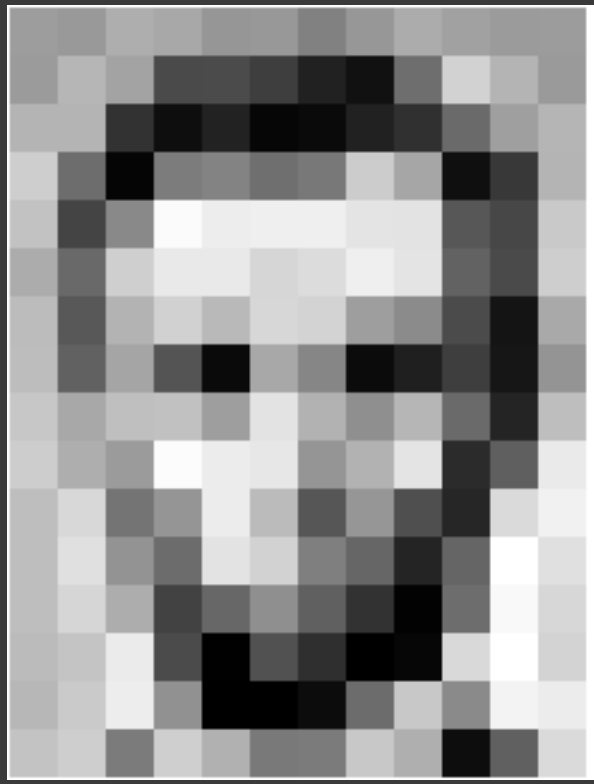




OBRAZ

2D tabulka pixelů



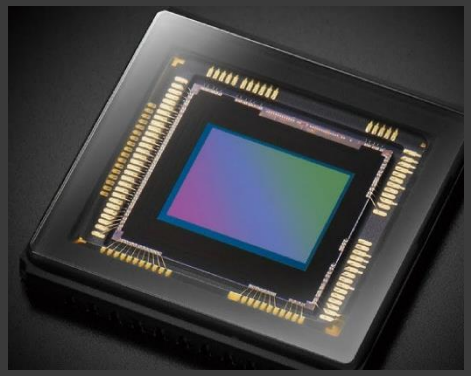


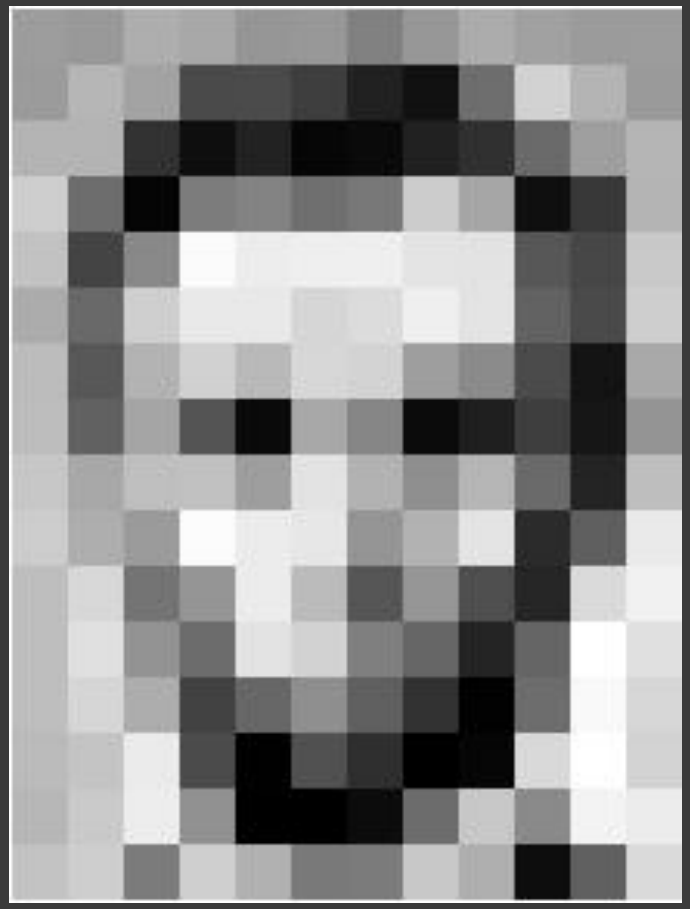
157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
196	206	123	207	177	121	123	200	175	13	96	218

157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
196	206	123	207	177	121	123	200	175	13	96	218

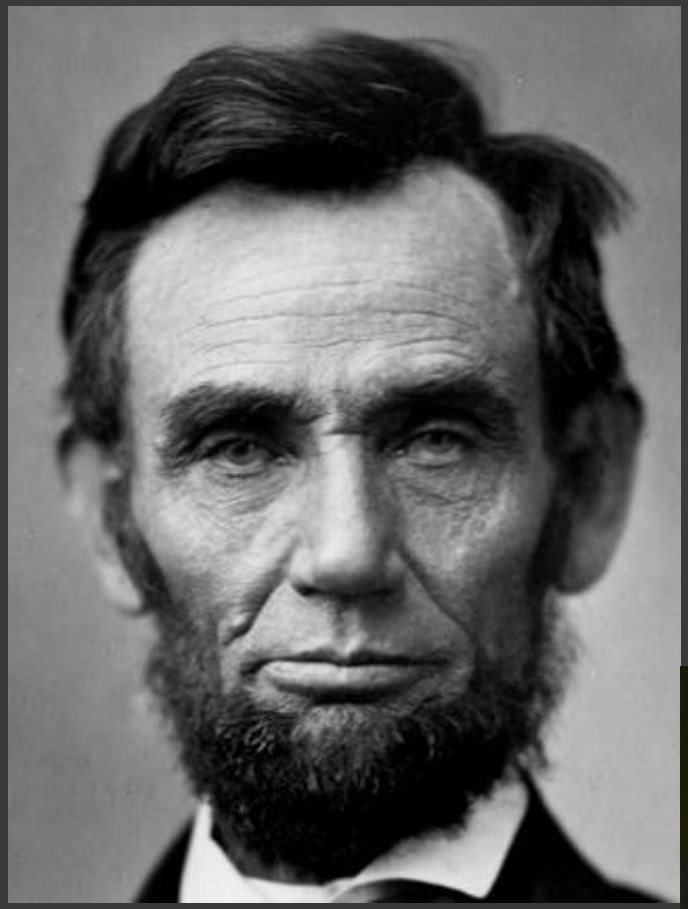
ROZLIŠENÍ

- Oko: 0,1-0,15mm
- Mikroskop: 0,00017mm, Abbeho limit, Numerická apertura, zvětšení objektivu, vlnová délka





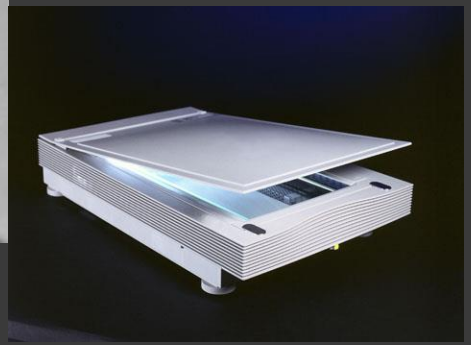
12 x 16 px



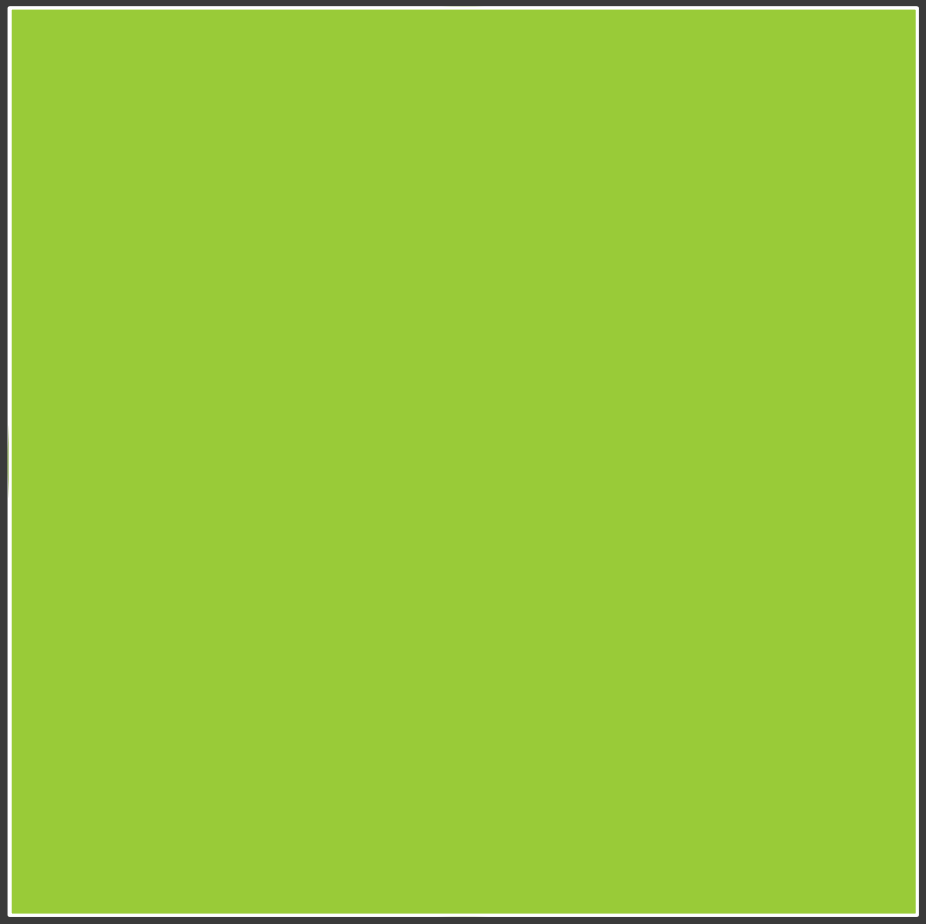
321 x 428 px

- počet pixelů
- CMOS/CCD čipy
- dpi – dots per inch

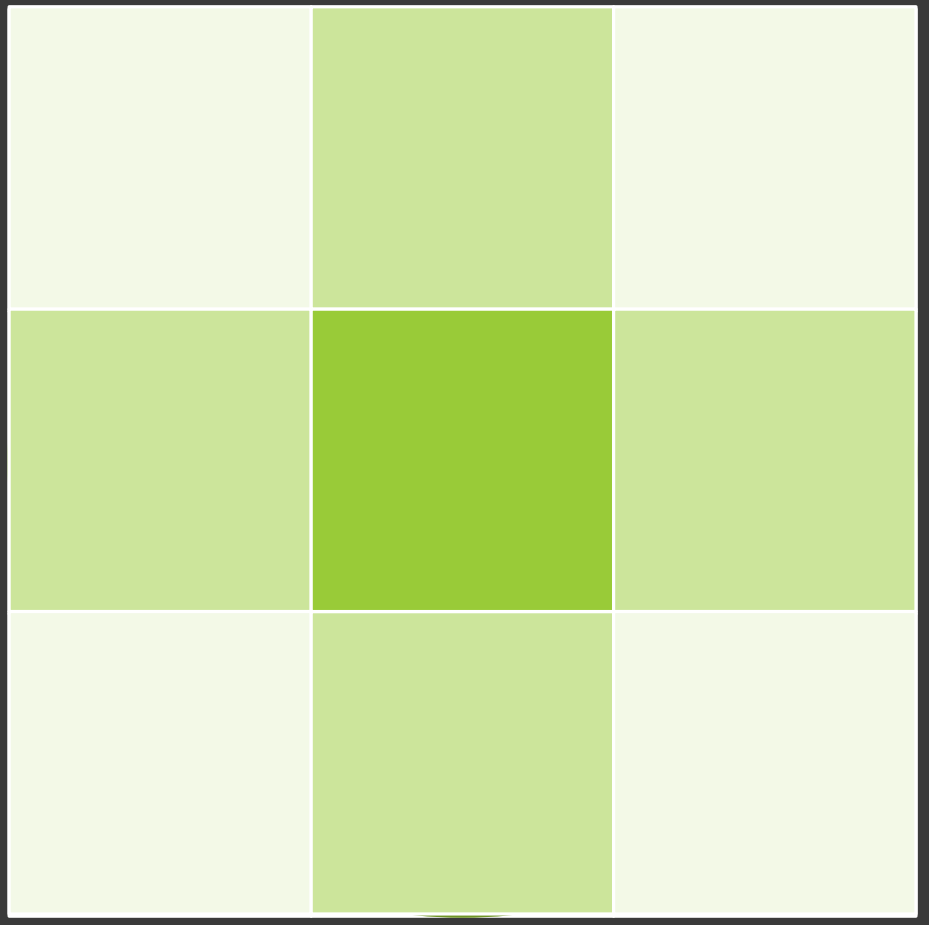
- tvar objektu vs. px
- zvětšení objektivu
- rozlišení objektivu



ROZLIŠENÍ



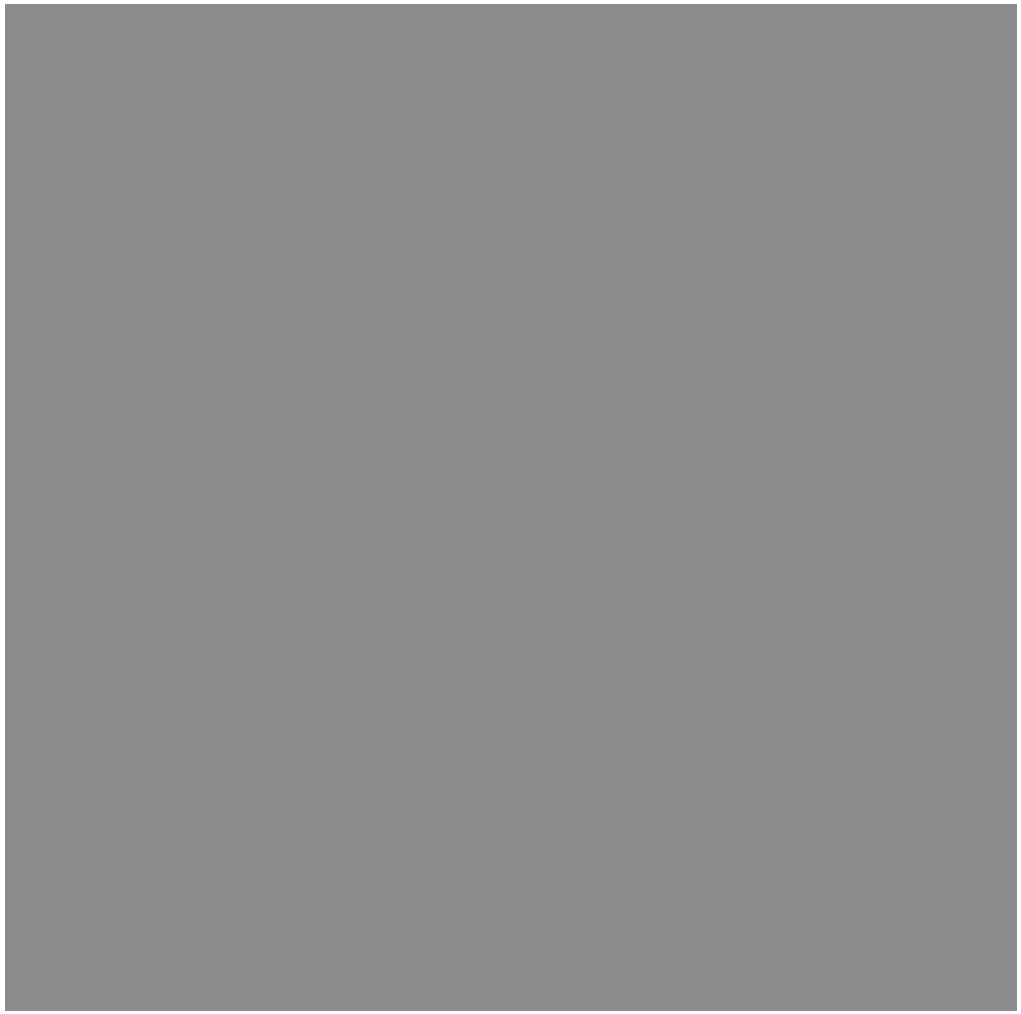
1 x 1 px



3 x 3 px

STUPNĚ ŠEDI

- Hladiny 150, 145, 140
- 30 stupňů šedi

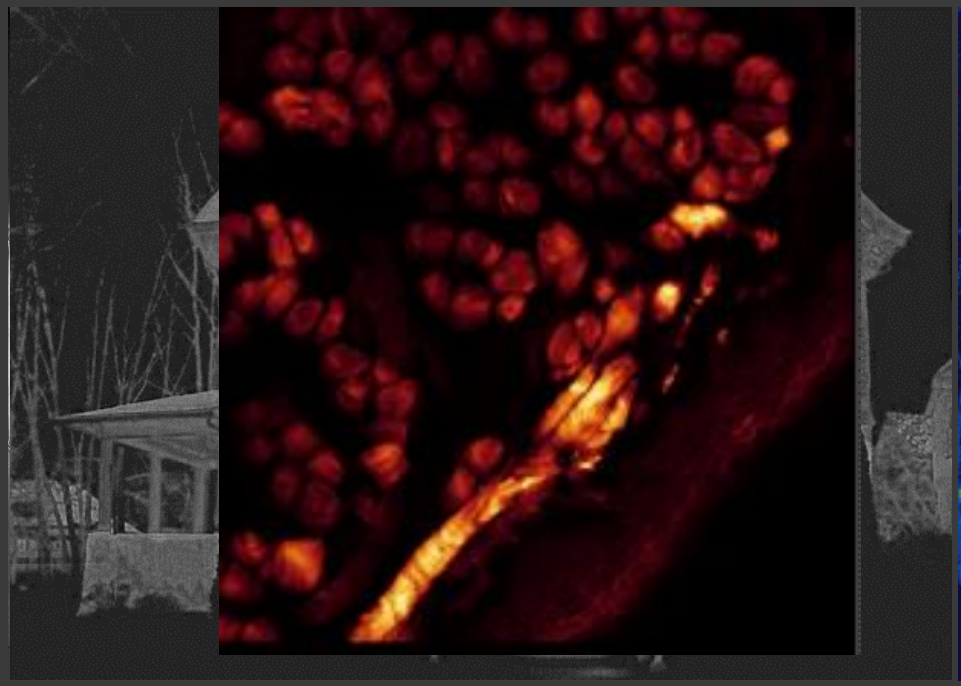


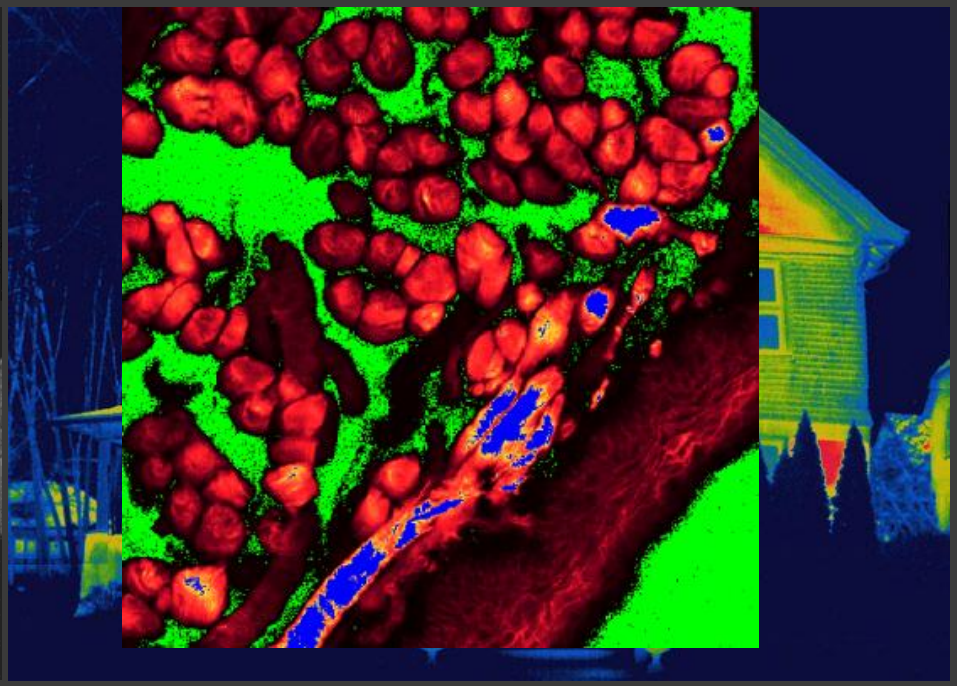
STUPNĚ ŠEDI

- okolo 900 stupňů šedi relativně

BAREVNÉ KÓDOVÁNÍ

- 10 milionů barev





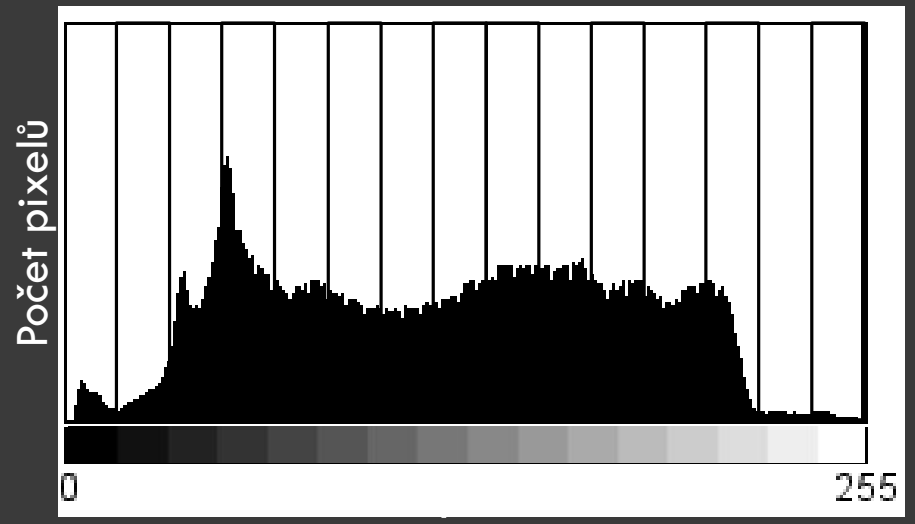
ImageJ:
Analyze → Histogram
Image → Type

HISTOGRAM – BITOVÁ HLOUBKA

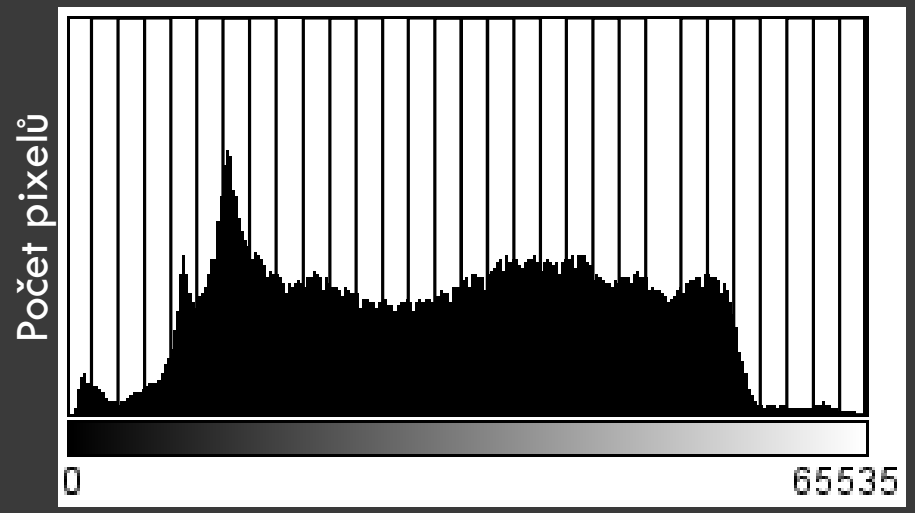
Originální obrázek

Histogram

Bitová hloubka

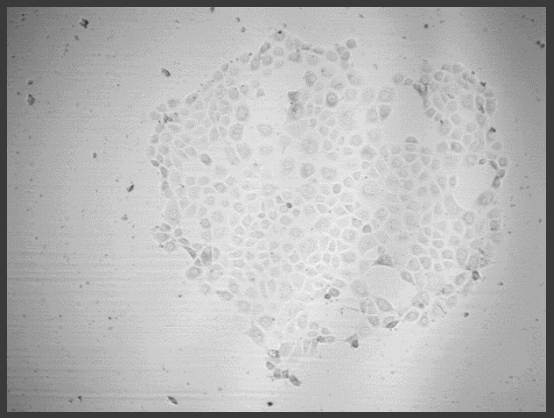


8 bit

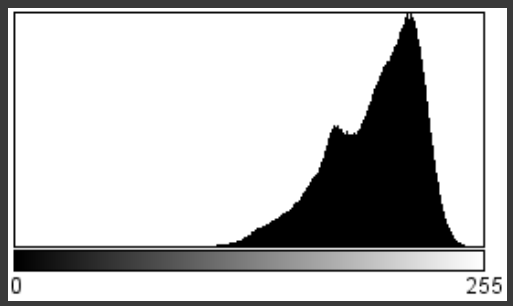


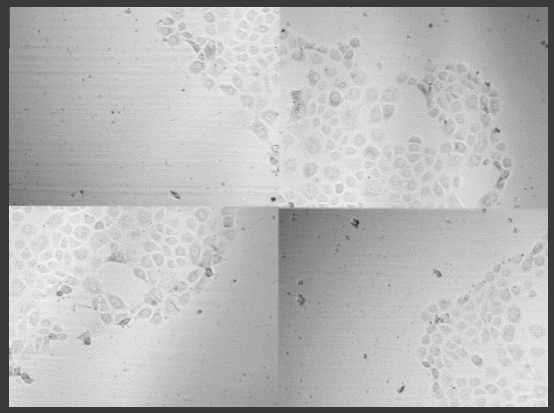
16 bit

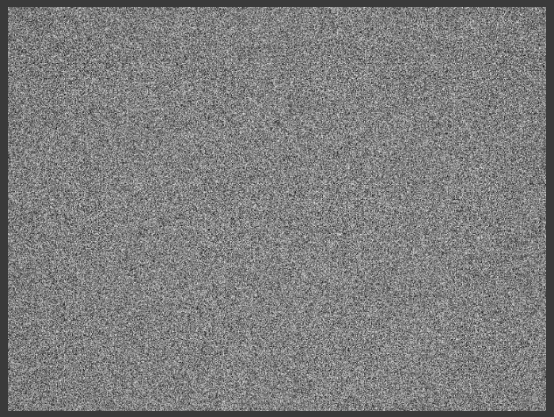
HISTOGRAM – REKONSTRUKCE OBRAZU



Histogram

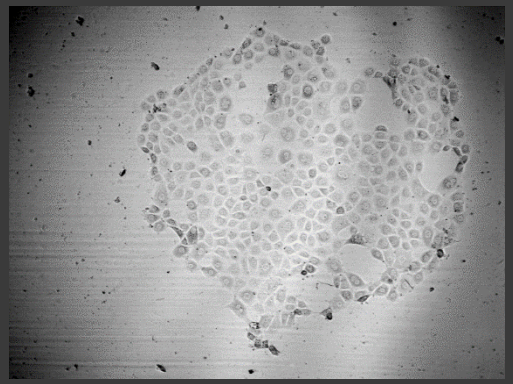




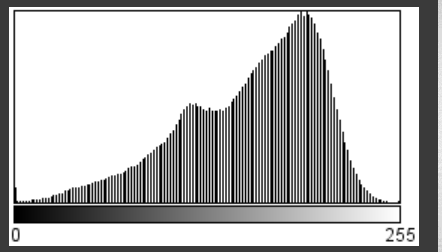


HISTOGRAM – DYNAMICKÝ ROZSAH

ImageJ:
Image → Adjust → Brightness/Contrast



Original

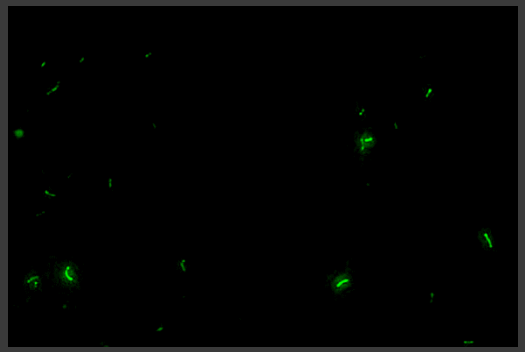


Velký dynamický rozsah

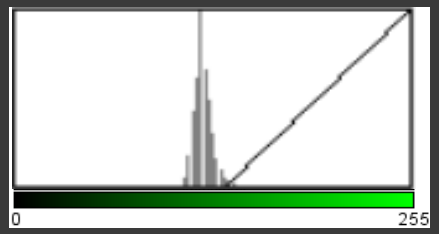
Histogram matching

Krátká expozice

Malý dynamický rozsah



Originál

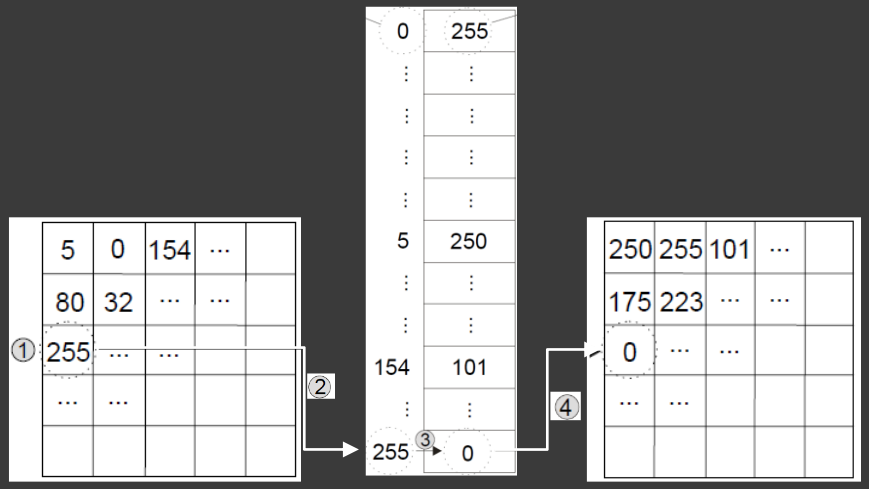


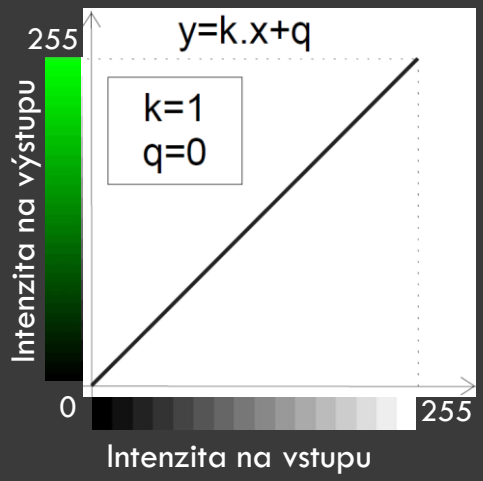
Odstranění pozadí

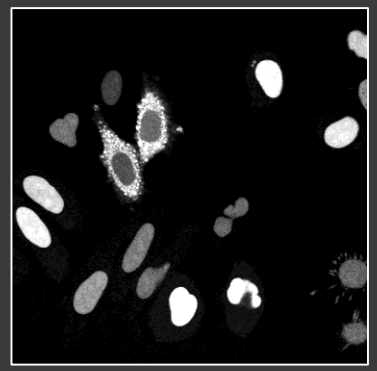
HISTOGRAM & LUT – LOOKUP TABLE

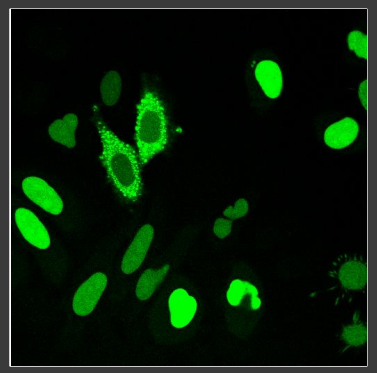
ImageJ:
Image → Lookup Tables → Invert LUT/Green

Jak LUT funguje





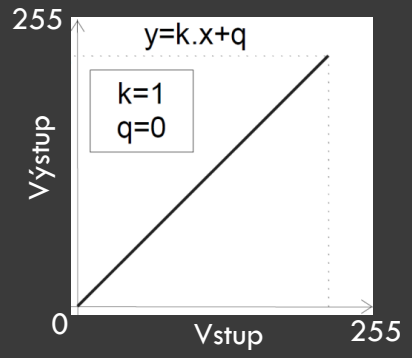


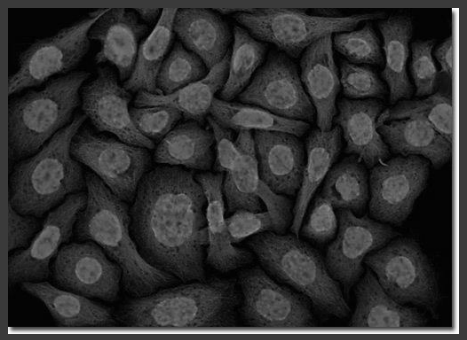


HISTOGRAM & LUT – PŘÍKLADY

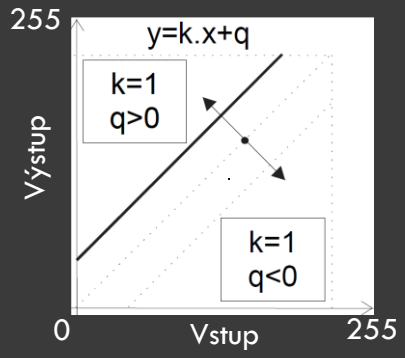
ImageJ:
Image → Adjust → Brightness/Contrast

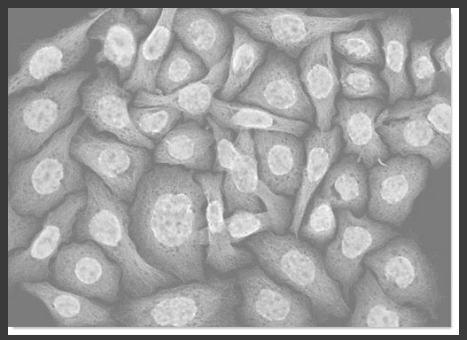
Žádná změna



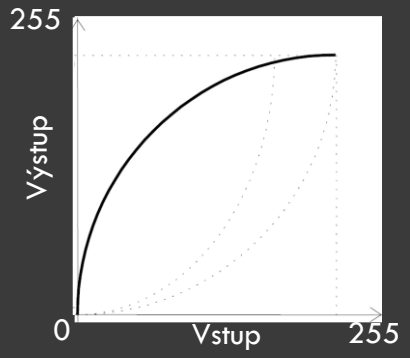


Jas



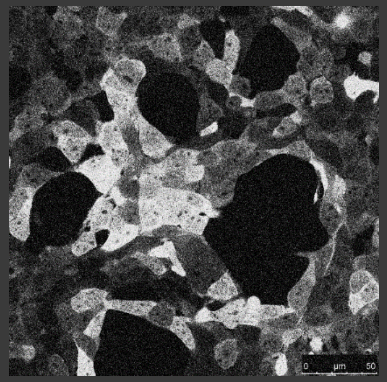


Gamma korekce

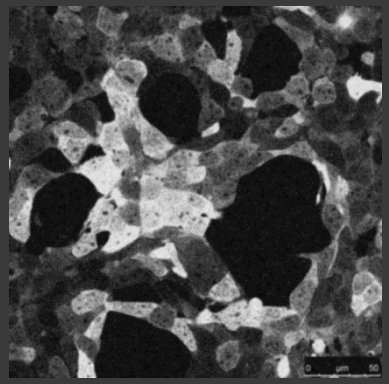


HISTOGRAM - ŠUM

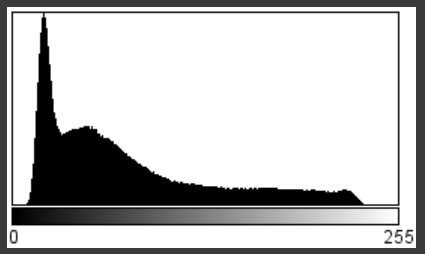
ImageJ:
Process → Filters → Gaussian Blur/Median

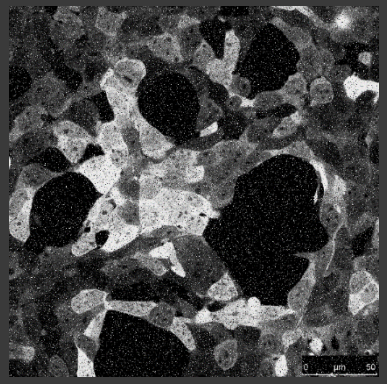


Gaussovský

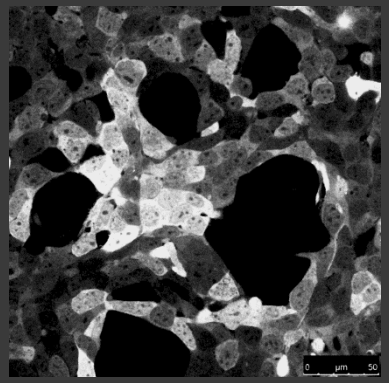


Blur filtering

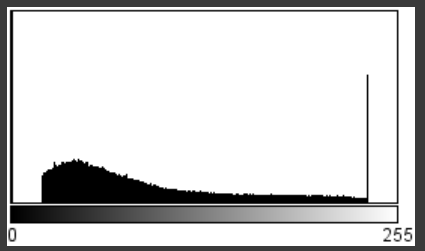




Sůl & Pepř

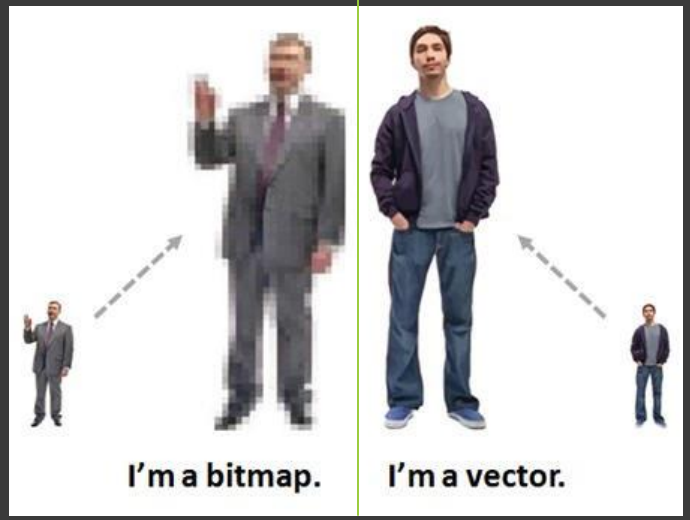


Median filtering



DATOVÉ FORMÁTY

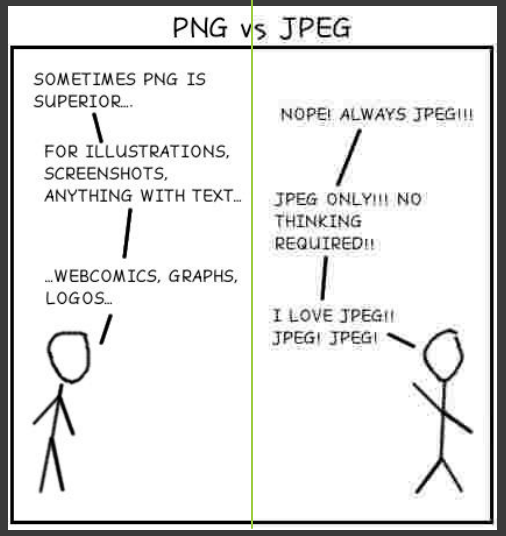
Rastrové obrazy	Vektorové obrazy
Tvar reprezentovaný maticí pixelů	Tvar složený z geometrických objektů
Pixelace	Jemná struktura
Fotorealistické obrazy	Diagramy, schémata, grafy, ilustrace
Typické formáty: JPEG, GIF, TIFF, PNG	Typické formáty: SVG, DWG, CDR, WMF



ImageJ:
File → Save As →
PNG/Jpeg

DATOVÉ FORMÁTY – RASTROVÁ GRAFIKA

Portable Network Graphics (PNG)	**Joint Photographic Expert Group (JPEG)**
Grafika, obrazy s textem, fotky	Fotky a realistické obrazy
Bezeztrátová komprese	Ztrátová komprese
Velké oblasti sytých barev, ostré přechody	Jemné, pozvolné přechody
Nepodporuje Non-RGB barevný prostor(CMYK)	Nepodporuje transparentnost



ImageJ:
File → Save As →
PNG/Jpeg

DATOVÉ FORMÁTY – RASTROVÁ GRAFIKA

Joint Photographic Expert Group (JPEG)

Fotky a realistické obrazy

Ztrátová komprese

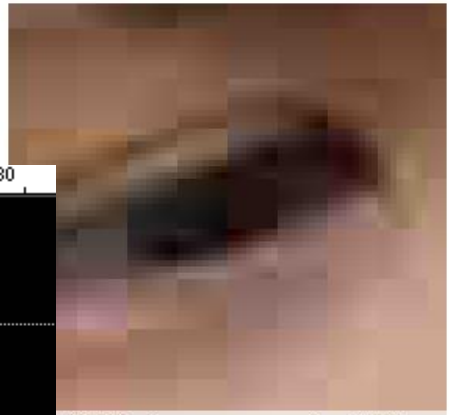
Jemné, pozvolné přechody

Nepodporuje transparentnost

Rozdělení na bloky 8x8 pixelů, 2D DCT

Lidský zrak je citlivý k relativně malé změně v jasu nebo v barvě na poměrně velké ploše. V rozlišování konkrétní síly rychle se měnícího jasu (vysokofrekvenční změny) je však mnohem horší.

6,25% jpeg compression 0/12

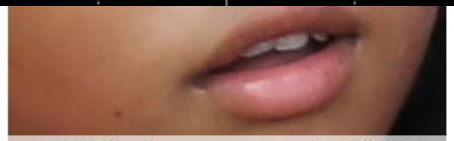


400% jpeg compression 0/12

25% jpeg compression 3/12

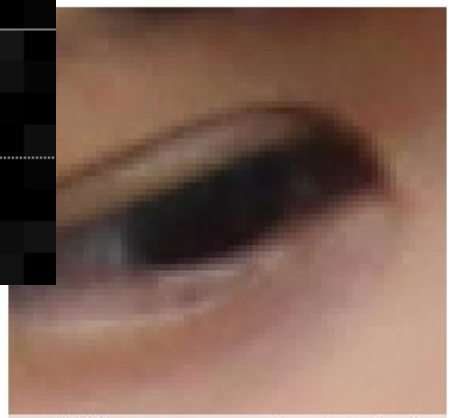
400% jpeg compression 6/12

100% jpeg compression 9/12



100% jpeg compression 12/12

400% jpeg compression 12/12

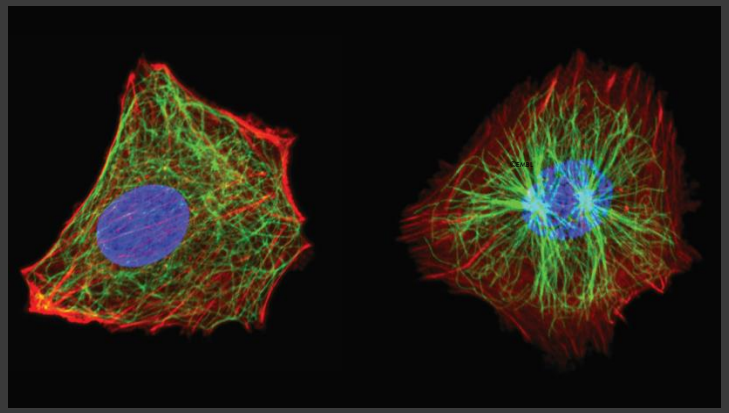


400% no compression (original)

ImageJ:
File → Save As →
Gif/Animated
Gif/Tiff/Compressed
TIFF

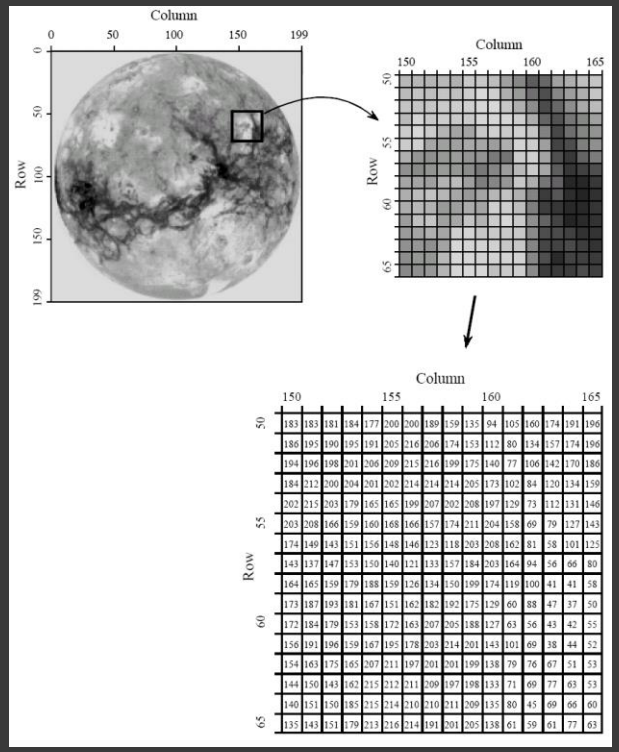
DATOVÉ FORMÁTY – RASTROVÁ GRAFIKA

Graphic Interchange Format (GIF)	**Tagged Image File Format (TIFF)**
Grafika, loga, animace	Fotky, grafika
Bezeztrátová komprese	Možnost bezeztrátové komprese
Velké oblasti sytých barev, ostré přechody	Profesionální, široce podporovaný
8bits/pixel, 256 barev z 24bit RGB prostoru	Různé barevné prostory, jakékoli rozlišení a barvy

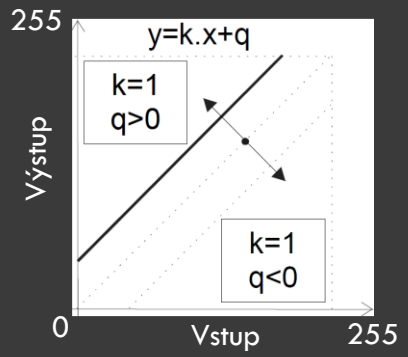


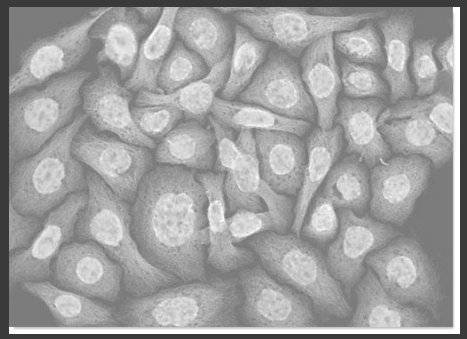
ZPRACOVÁNÍ – BODOVÉ TRANSFORMACE

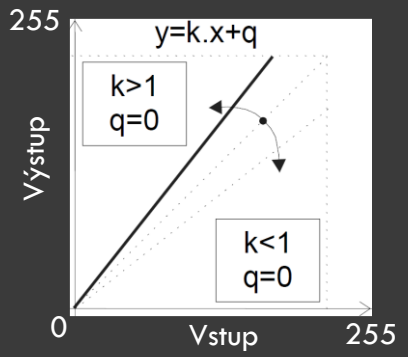
ImageJ:
Image → Adjust → Brightness/Contrast

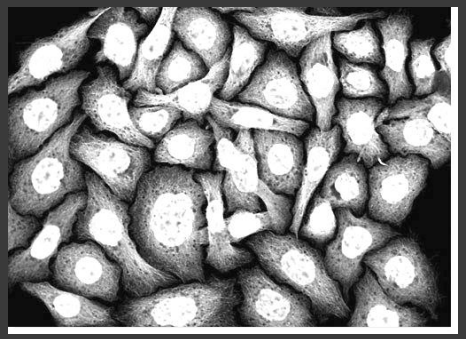


*30



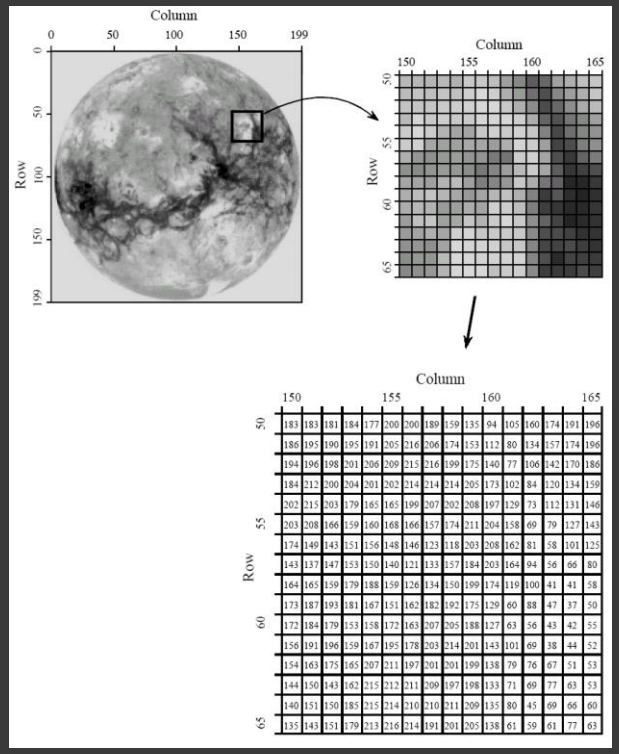


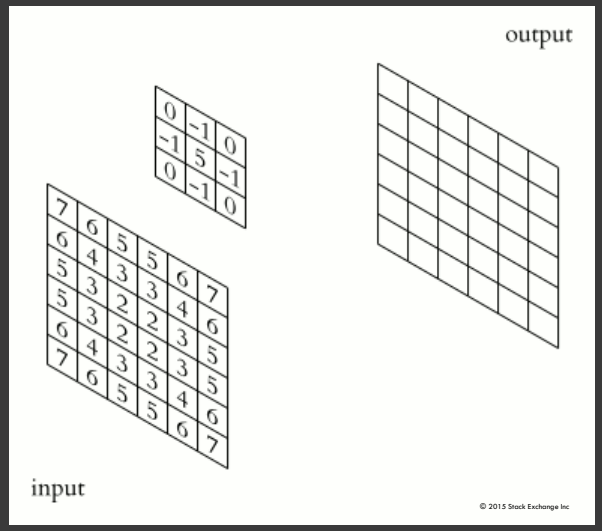


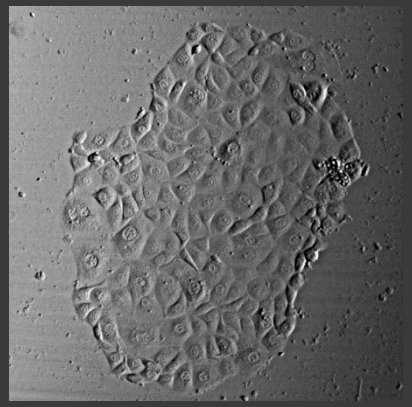


FILTROVÁNÍ – LOKÁLNÍ ZMĚNY

ImageJ:
Process →
Sharpen/Filters →
Unsharp Mask







FILTROVÁNÍ – PŘÍKLADY

ImageJ:
Process → Sharpen/Smooth/Find Edges
Plugins → Parallel Iterative Deconvolution

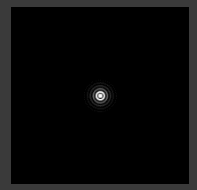
0	0	0	0	0
0	0	-1	0	0
0	-1	5	-1	0
0	0	-1	0	0
0	0	0	0	0

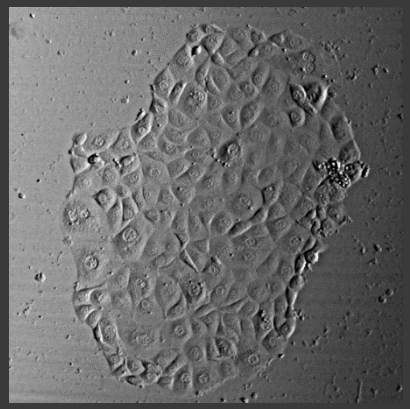
doostření

0	0	0	0	0
0	1	1	1	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

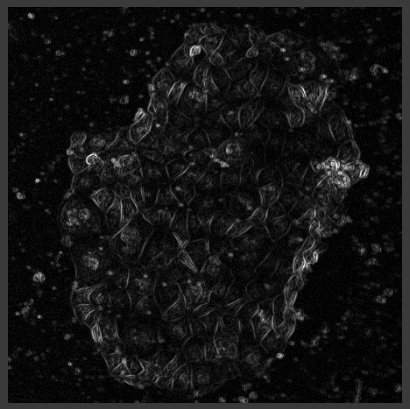
rozmazání

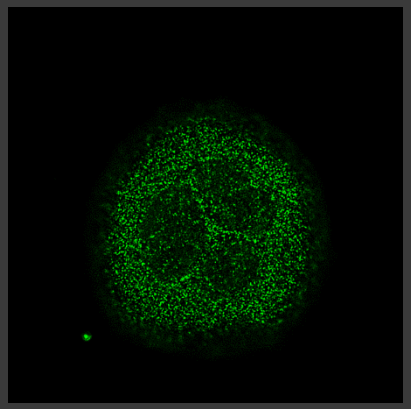
	0	1	0	
	1	-4	1	
	0	1	0	





detekce hran



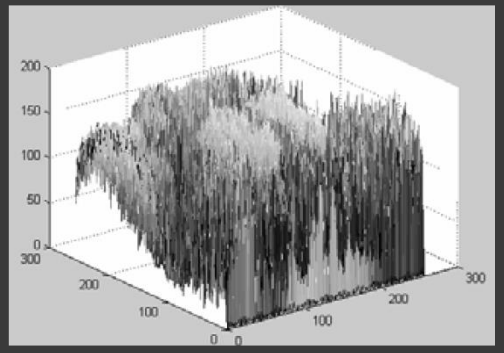


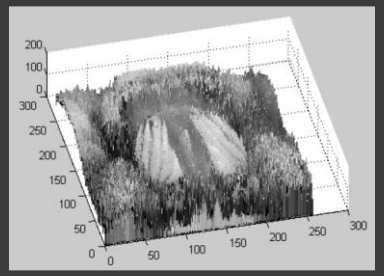
dekonvoluce

ImageJ:
Process ⟶ FFT ⟶ FFT

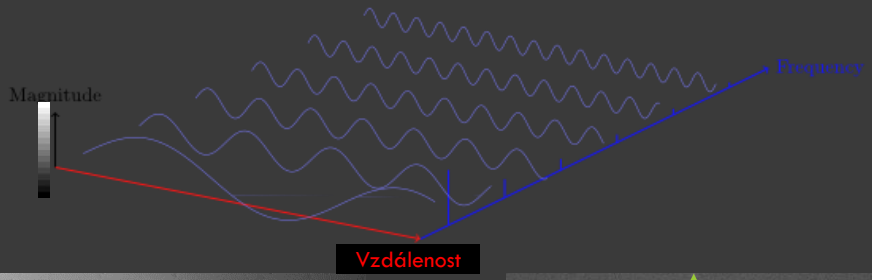
FILTROVÁNÍ – GLOBÁLNÍ TRANSFORMACE

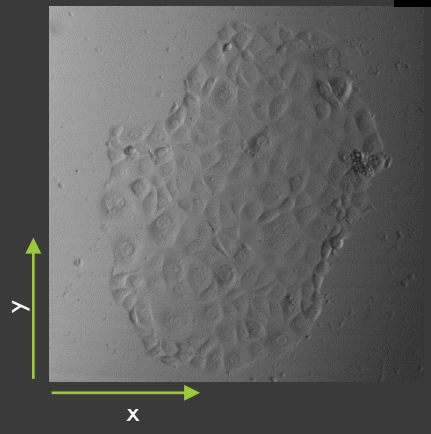
Fast Fourier Transformation

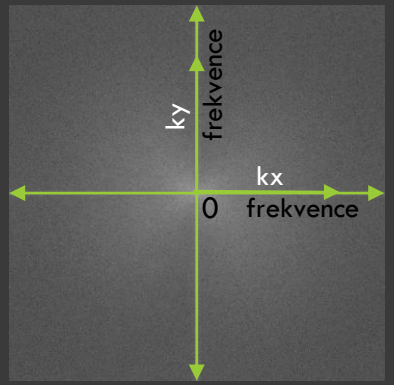




Konvoluce = Násobení



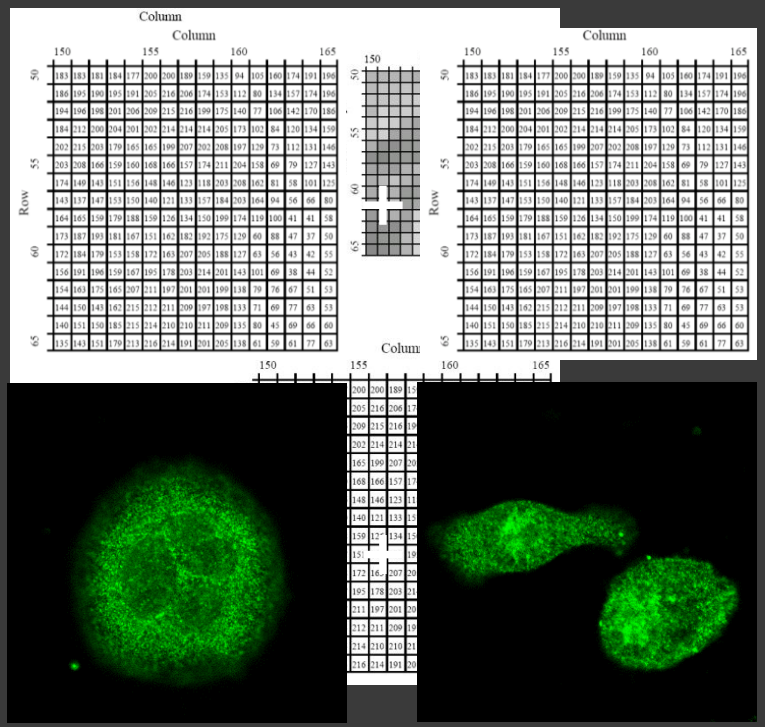




ImageJ:
Process → Image Calculator

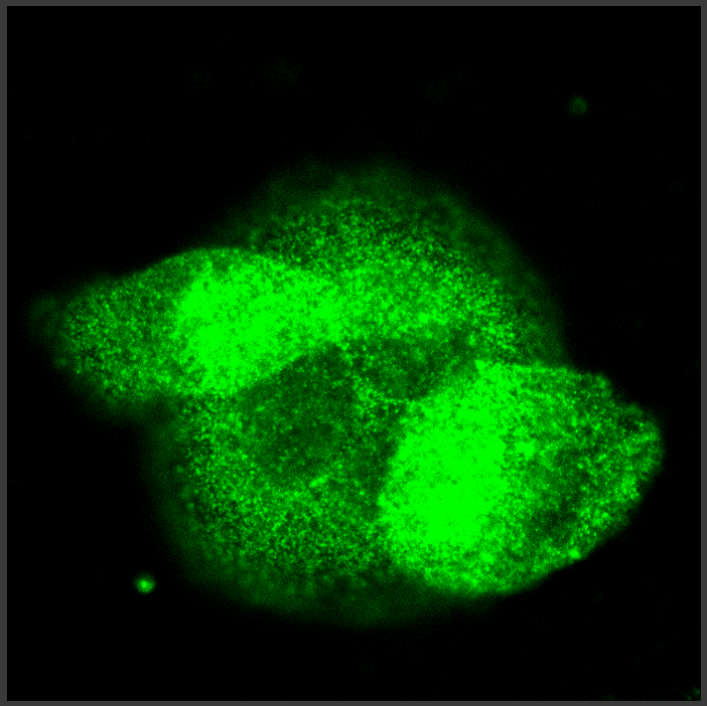
OBRAZOVÁ ARITMETIKA

Sčítání



=

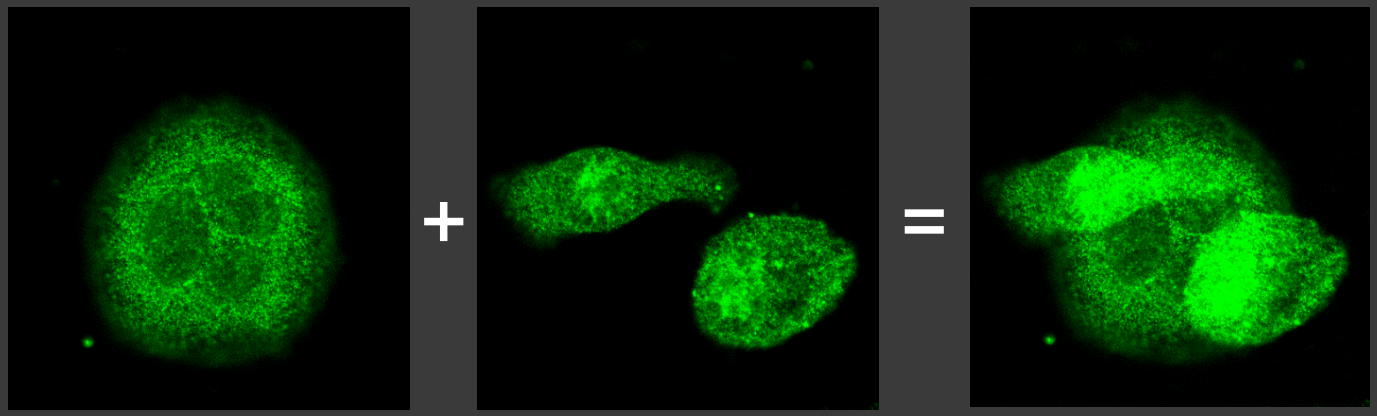
=



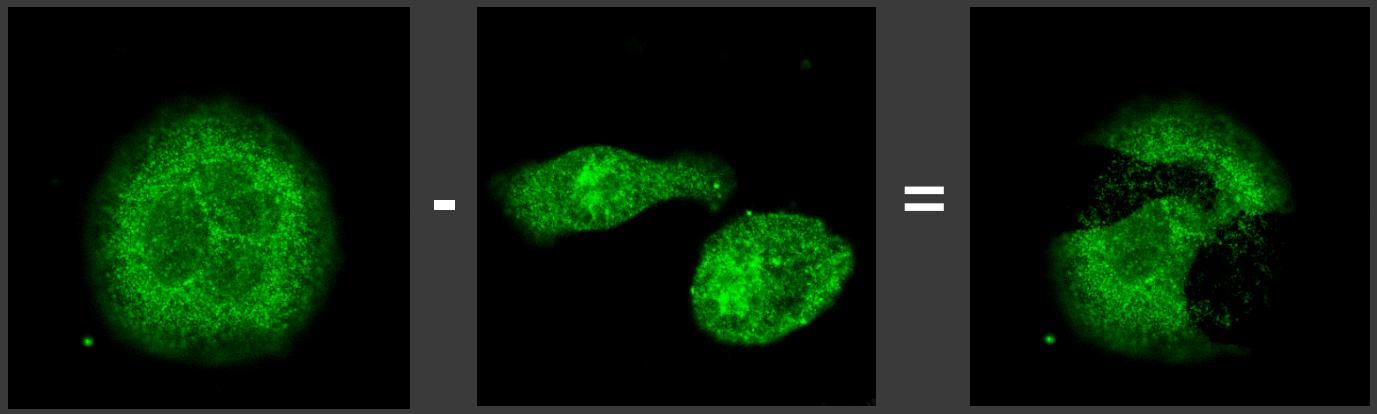
ImageJ:
Process → Image Calculator

OBRAZOVÁ ARITMETIKA

Sčítání



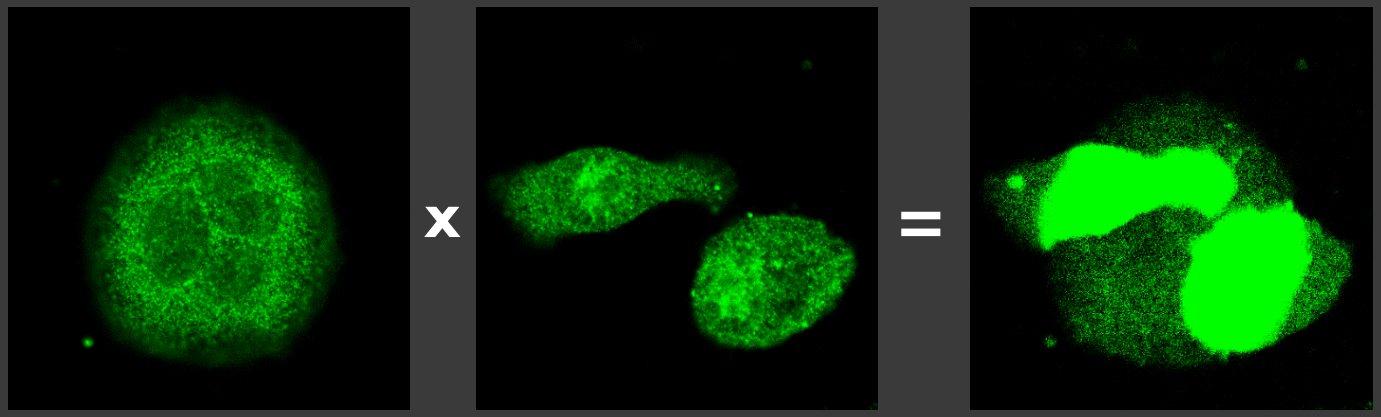
Odčítání



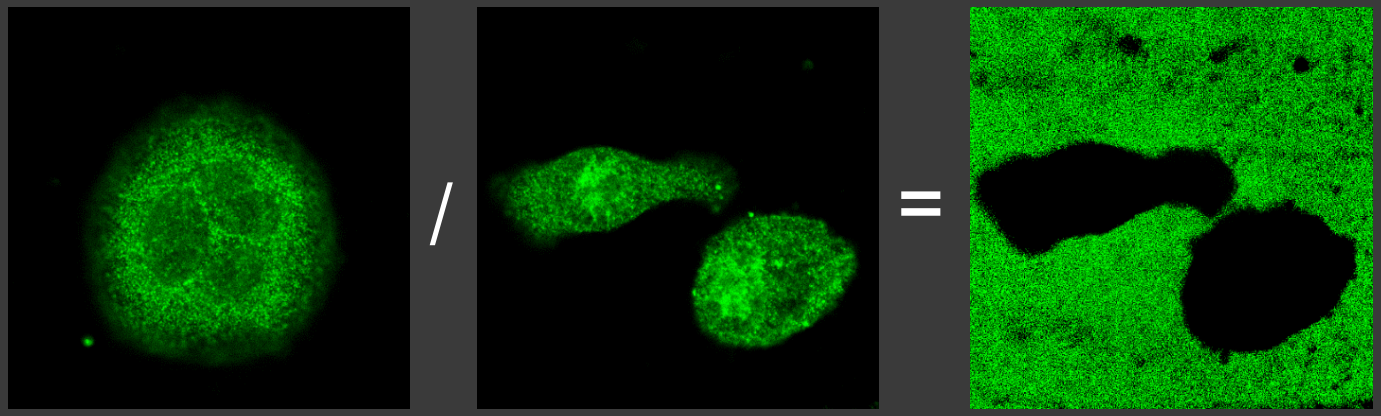
ImageJ:
Process → Image Calculator

OBRAZOVÁ ARITMETIKA

Násobení



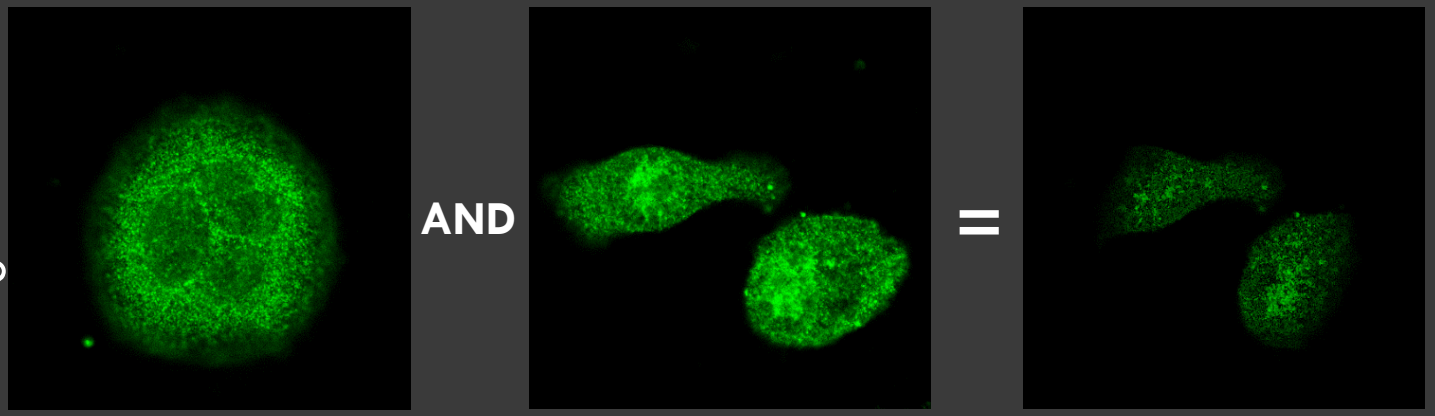
Dělení



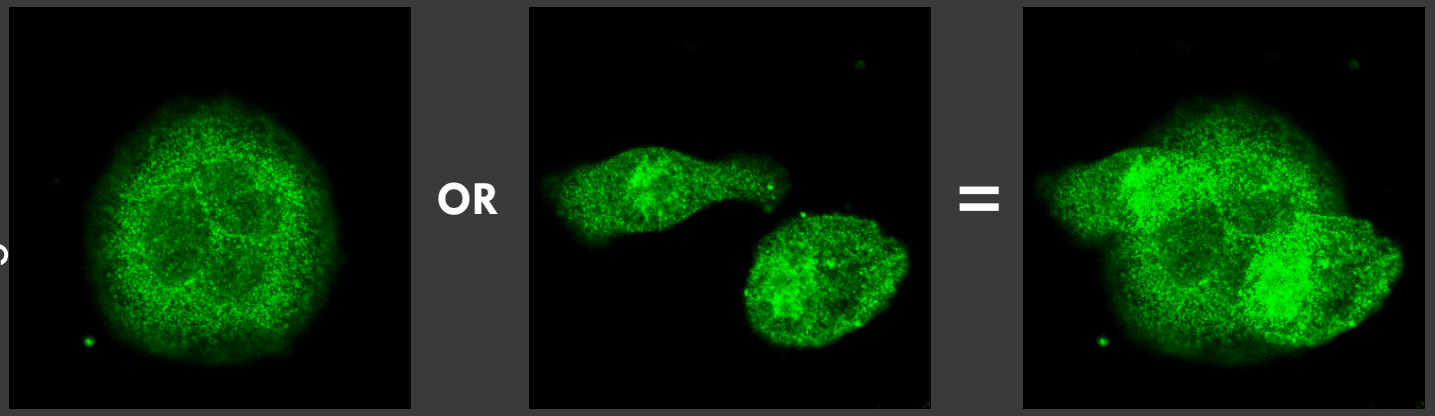
OBRAZOVÁ ARITMETIKA

ImageJ:
Process → Image Calculator

Logické AND



Logické OR

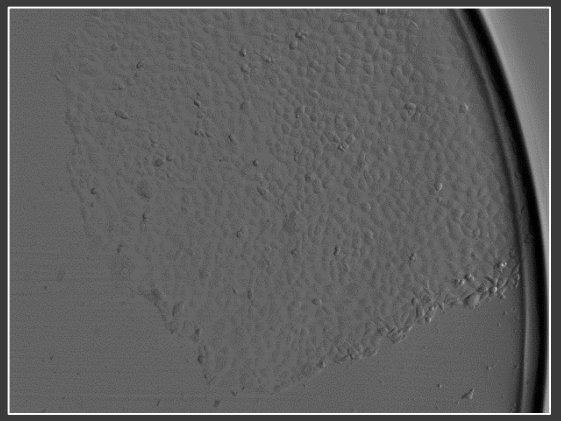


OBRAZOVÁ ARITMETIKA – PŘÍKLADY

ImageJ:
Process → Filters → Gaussian Blur → Save As
Process → Image Calculator

Flat Field korekce

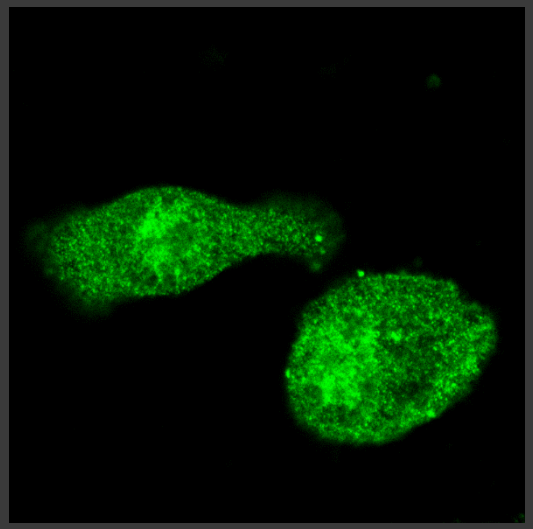

/

Gaussian blur
=


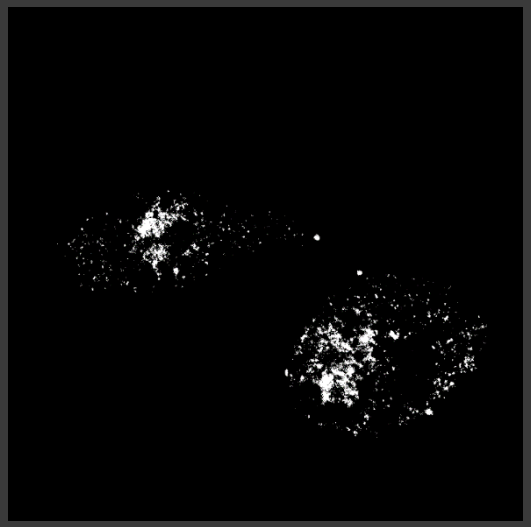
OBRAZOVÁ ARITMETIKA – PŘÍKLADY

ImageJ:
Image → Adjust → Threshold → Save As
Process → Image Calculator

Segmentace

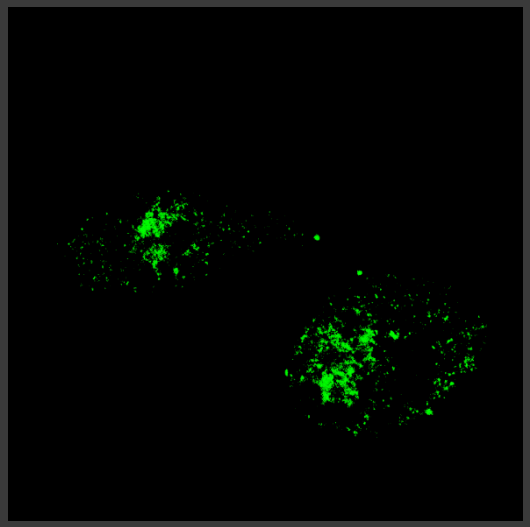


AND



Maska

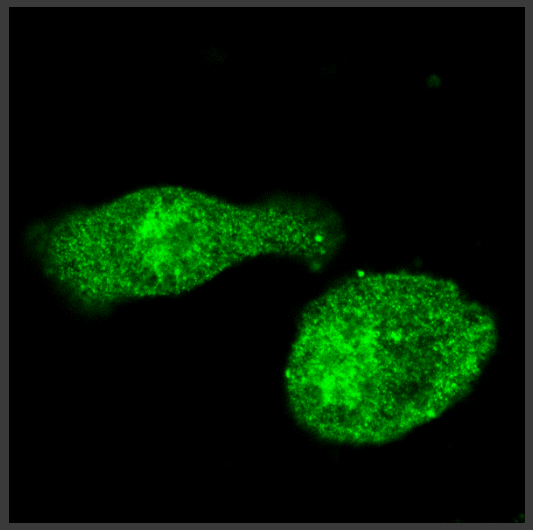
=



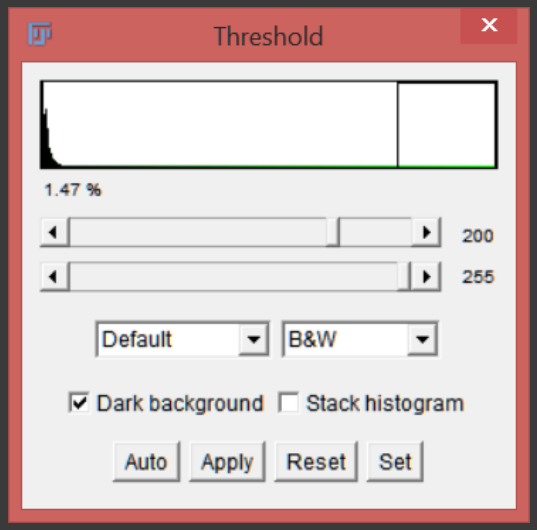
ImageJ:
Image → Adjust → Threshold

SEGMENTACE – MANUÁLNÍ PRAHOVÁNÍ TRESHOLDING

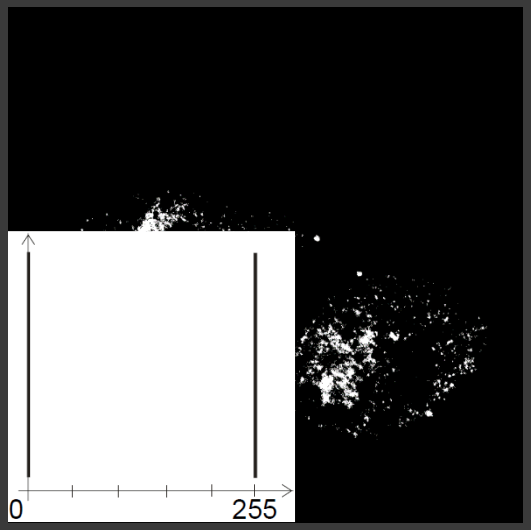
Originální obraz



Prahování



Maska

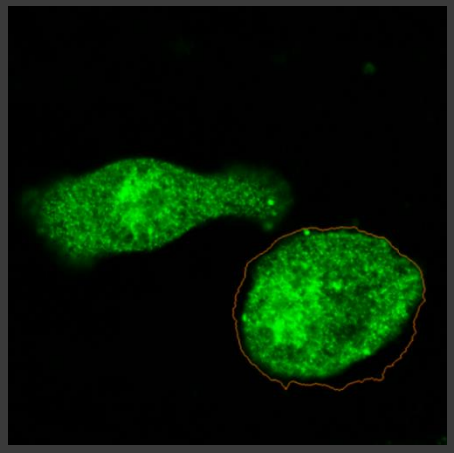


ImageJ:
Plugins →
Segmentation →
Level Sets

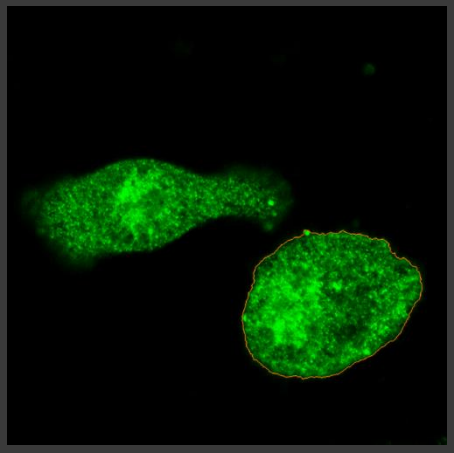
SEGMENTACE – POLOAUTOMATICKÁ

Start - ROI

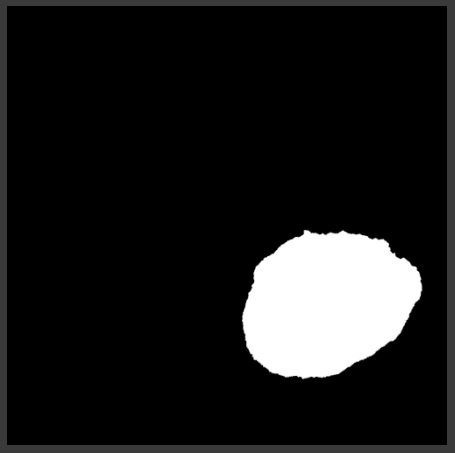
Level sets



Konec

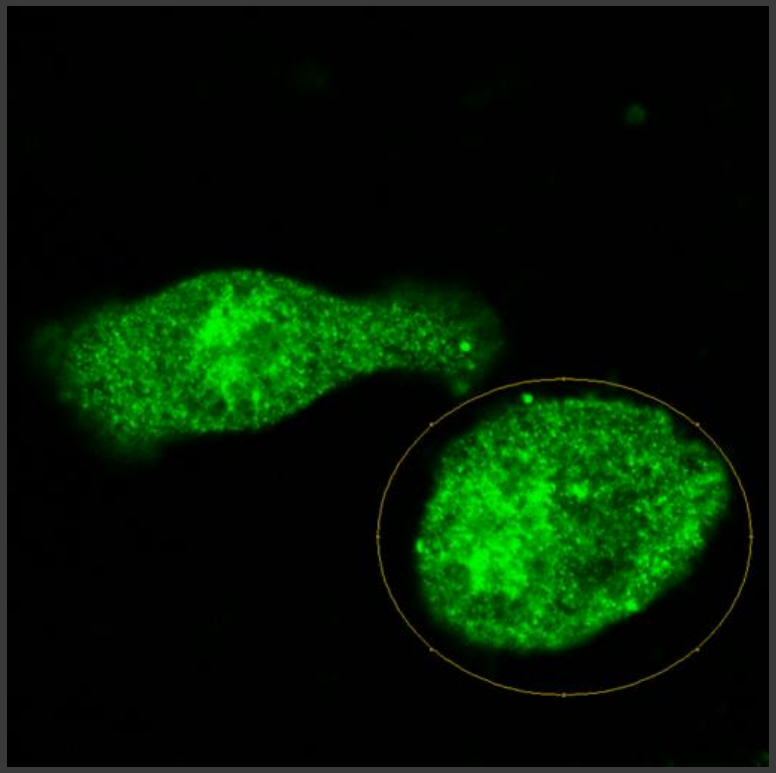


Maska



SEGMENTACE – POLOAUTOMATICKÁ

ImageJ:
Plugins →
Segmentation →
Level Sets

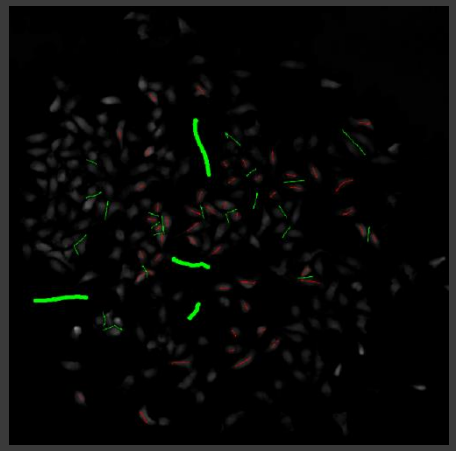


Ilastik:
Pixel Classification
→ Input Data →
Feature Selection →
Training →
Prediction Export

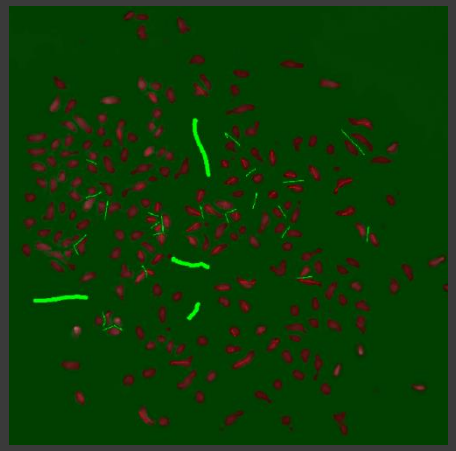
SEGMENTACE – STROJOVÉ UČENÍ

Originální obraz

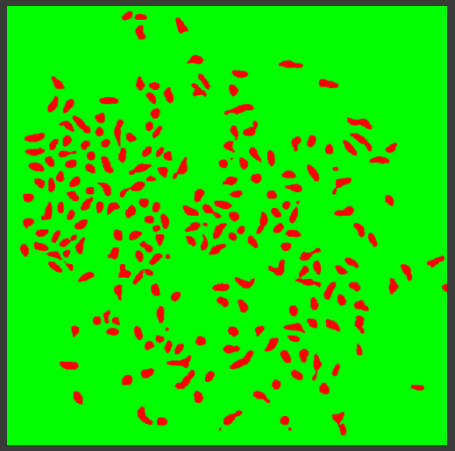
Učení malováním



Kontrola a oprava



Maska

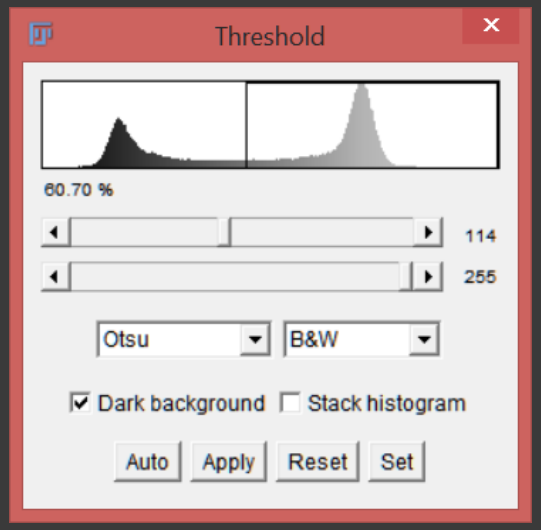


SEGMENTACE – AUTOMATIZOVANÁ

ImageJ:
Image → Adjust → Threshold → Otsu

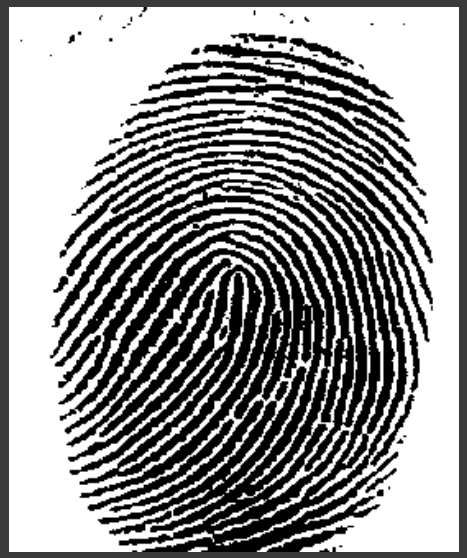
Originální obraz

Otsu - Klastrování



Intra-class variance minimal

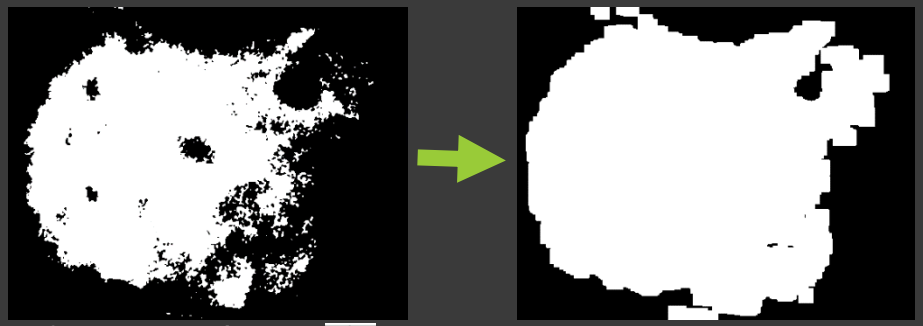
Segmentovaný obraz



ZMĚNA MORFOLOGIE MASKY

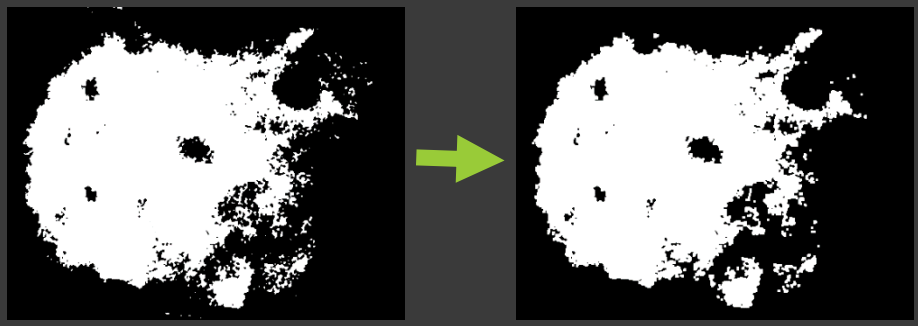
ImageJ:
Process → Binary → Make Binary
Process → Binary → Dilate/Erode/Open/Close

Roztažení

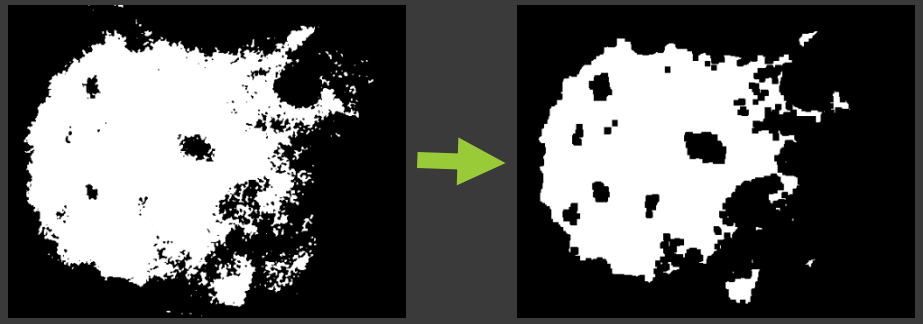


+ Structuring element 

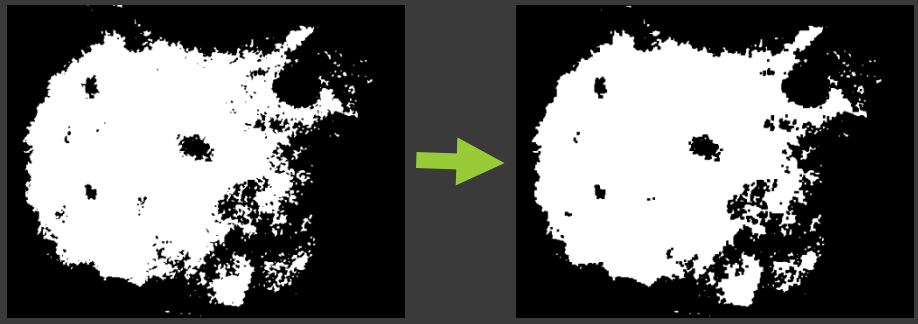
Otevření



Eroze



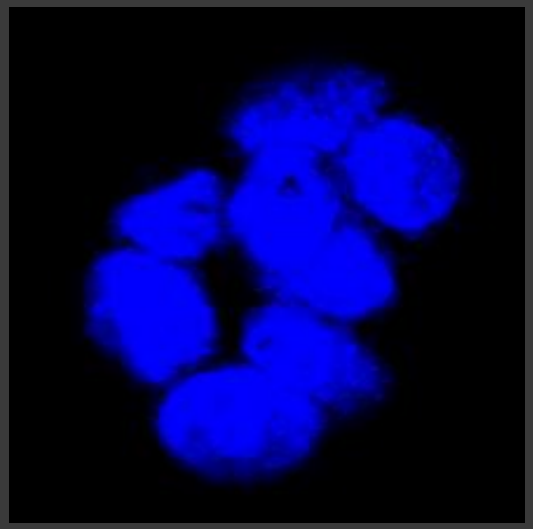
Zavření



ImageJ:
Process → Binary → Make Binary
Process → Binary → Watershed

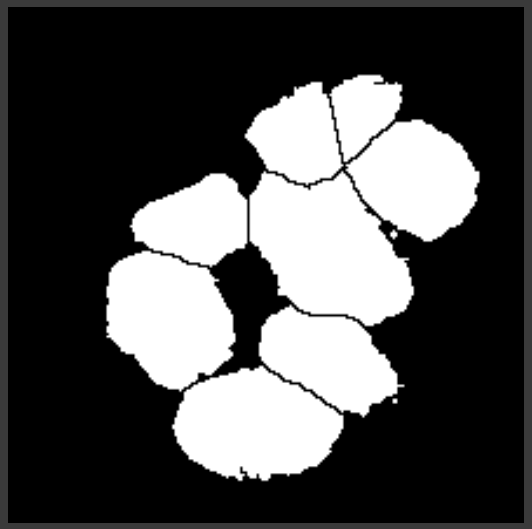
ZMĚNA MORFOLOGIE MASKY

Originální obrazy



Prahování

Watershed



Voda stéká do údolí

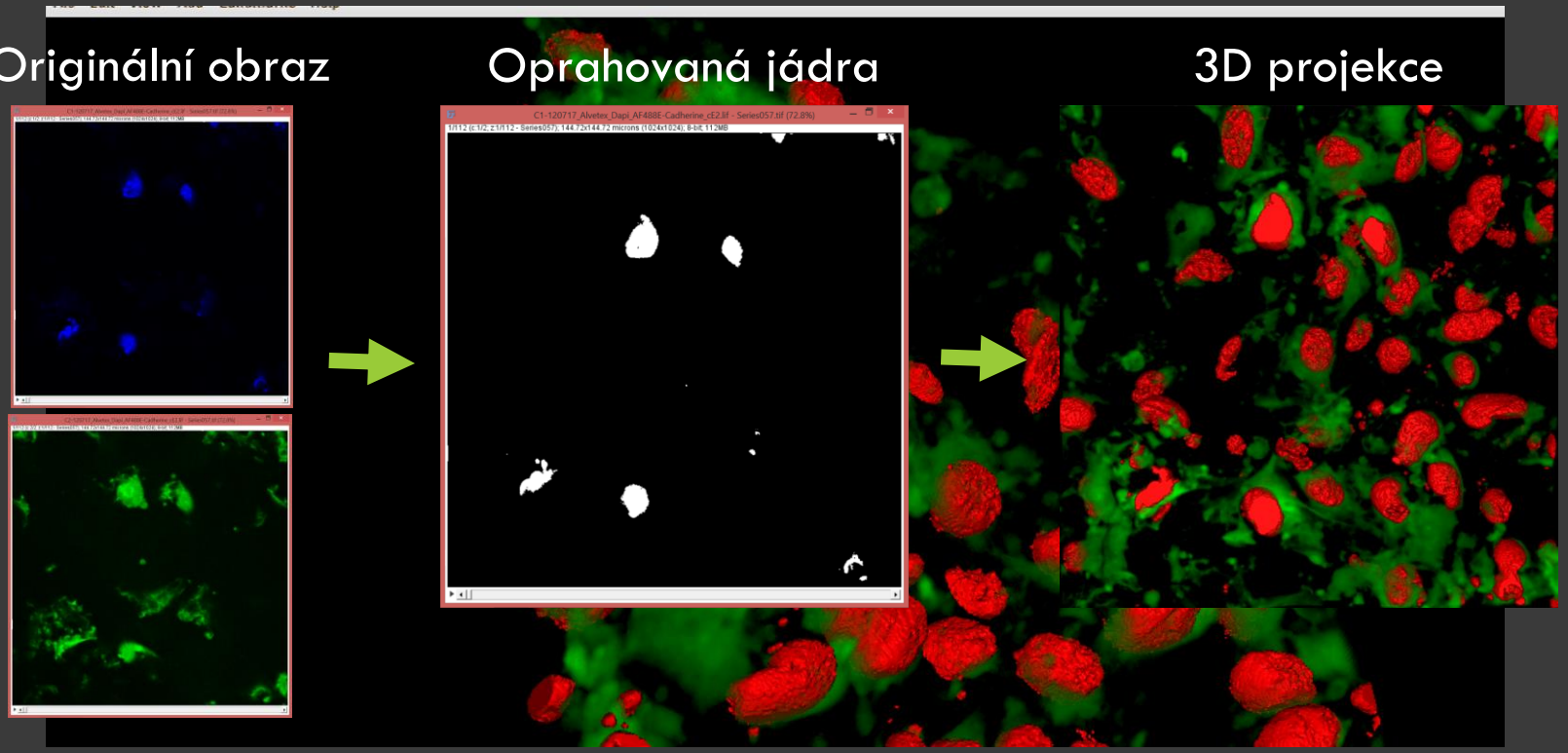
ImageJ:
Image → Adjust → Threshold → Otsu
Plugins → 3D Viewer

SEGMENTACE – 3D MODELOVÁNÍ

Originální obraz

Oprahovaná jádra

3D projekce



ANALÝZA - SOFTWARE

CellProfiler

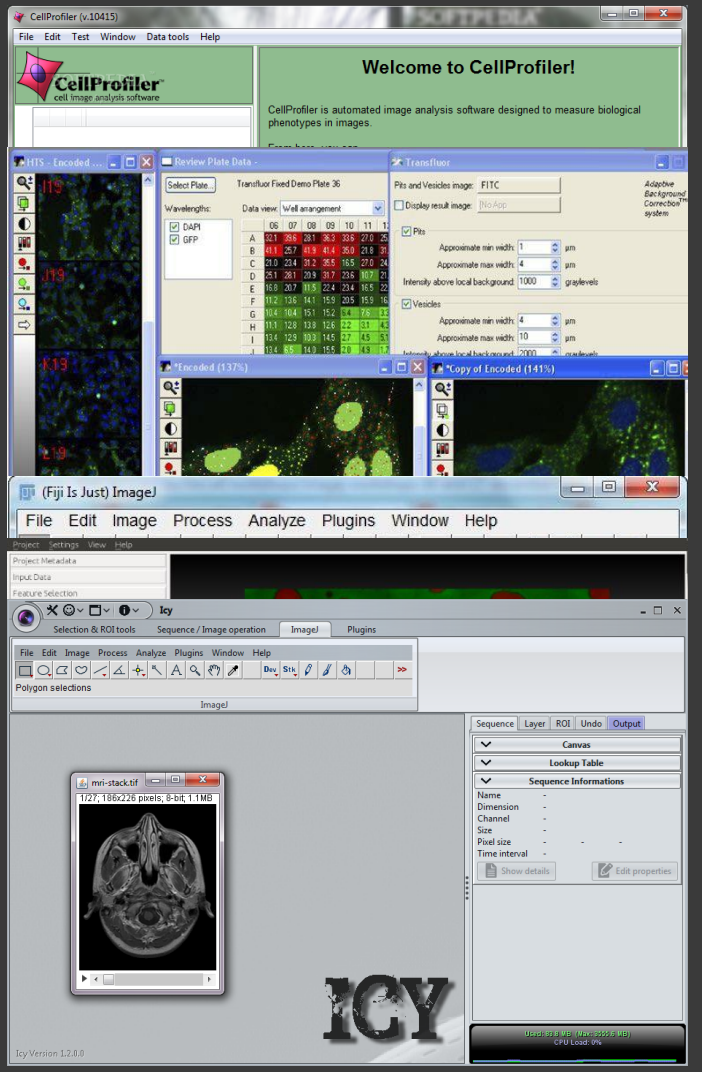
MD Metaxpress

LAS X

FIJI / ImageJ

Ilastik

Icy



ImageJ:
Image → Properties
Analyze → Analyze Particles

OBRAZOVÁ ANALÝZA - STEREOLOGIE

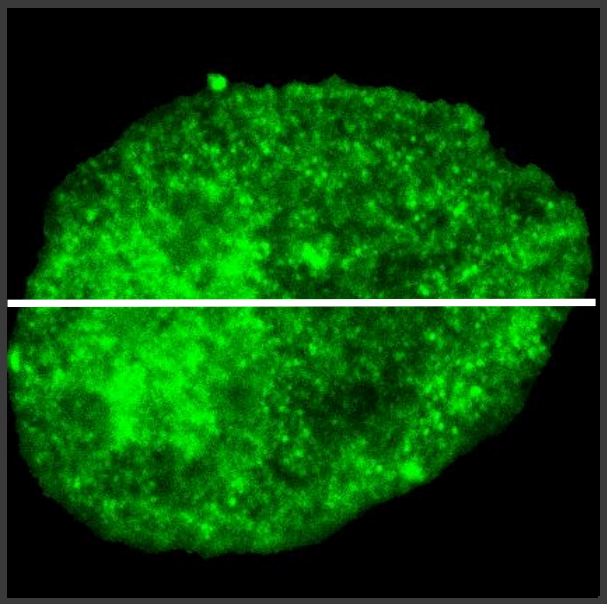
Velikost pixelu

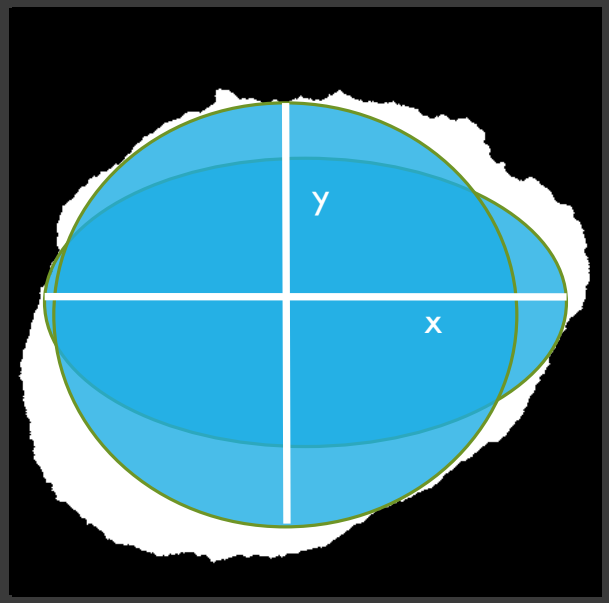
Plocha

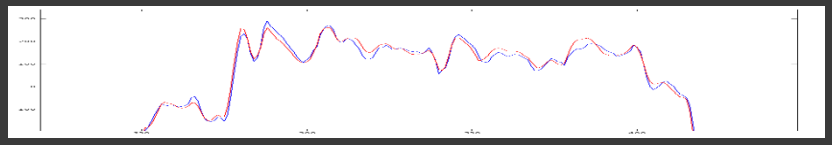
Intenzita (bitová hl.)

Textura

Morfologie

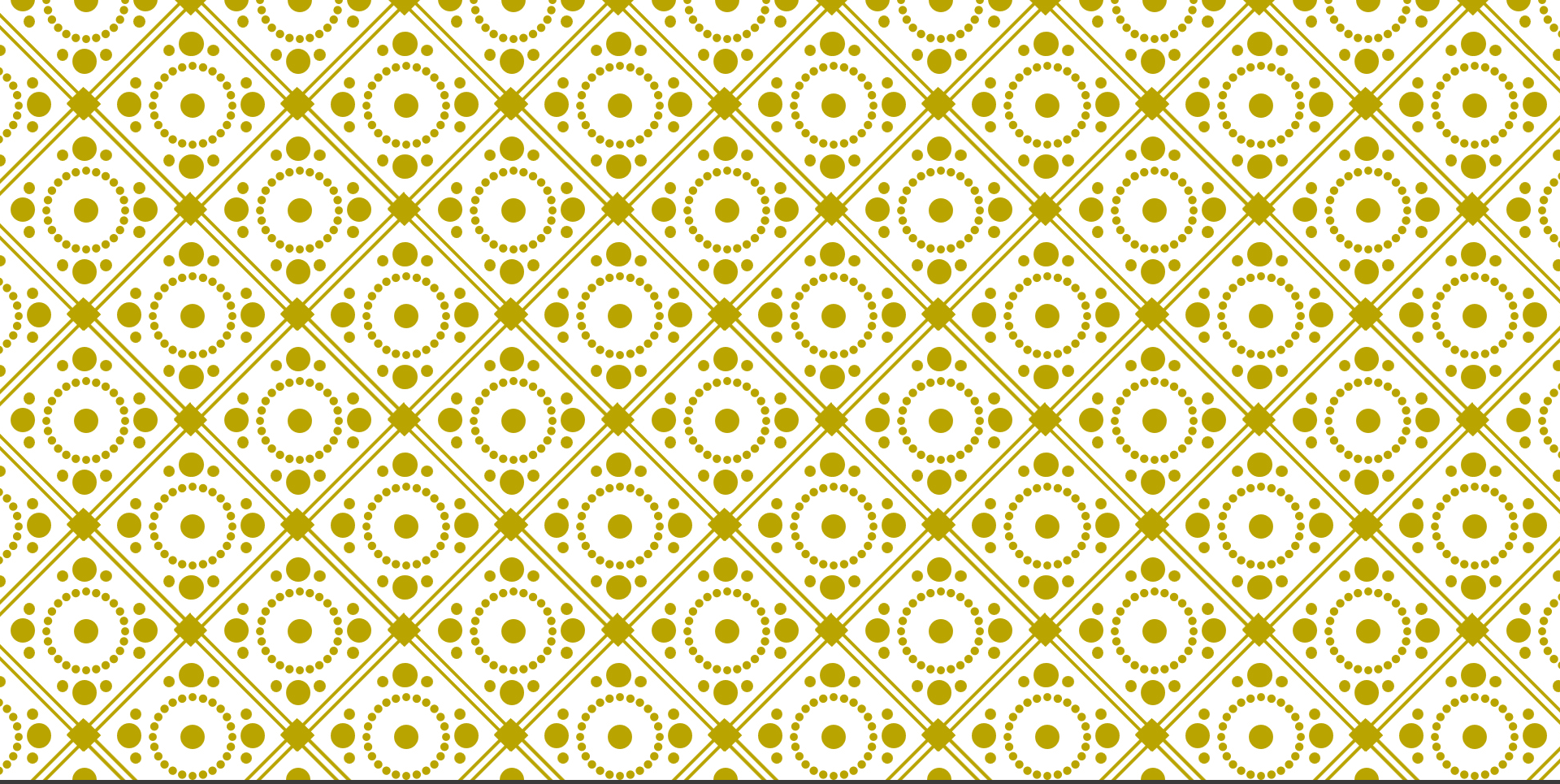






PROBLÉMY

- Doba snímání
- Titrace, výběr protilátky, fluorochrom, fixace



APLIKACE

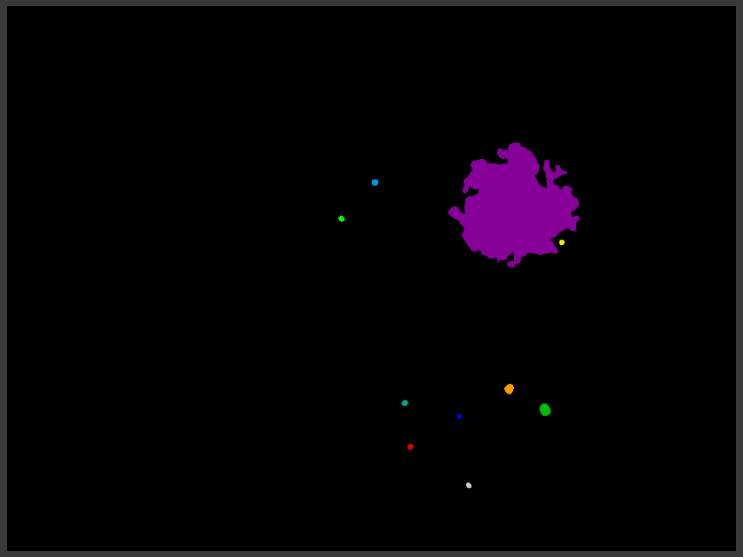
Příklady analýz

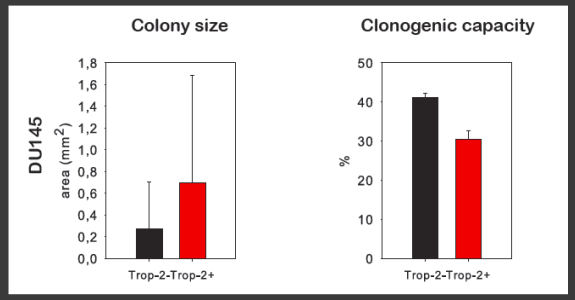
PRAKTICKÁ UKÁZKA

ANALÝZA SFEROIDŮ

POČÍTÁNÍ BUNĚČNÝCH KOLONIÍ

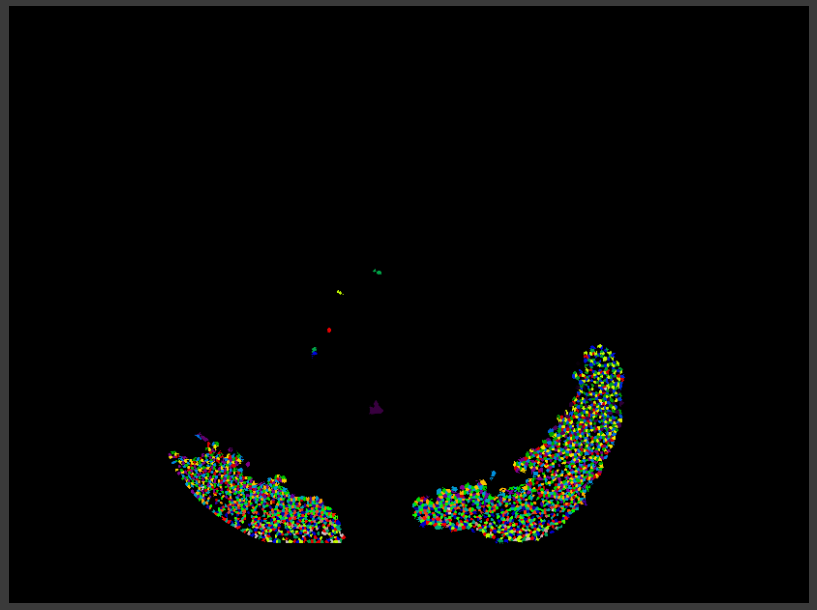
- Hightroughput
- Průchozí světlo
- Velikost kolonie
- Klonogenní kapacita
- Testování léčiv

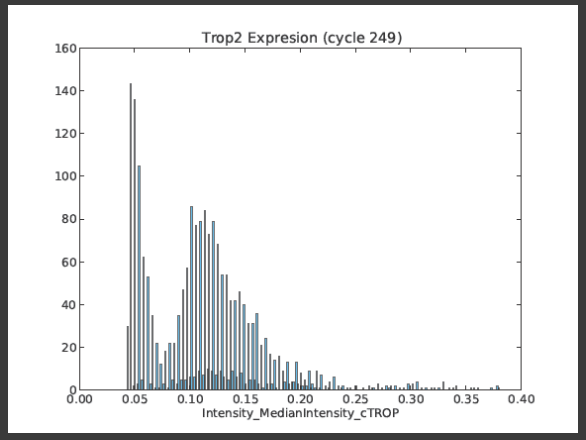




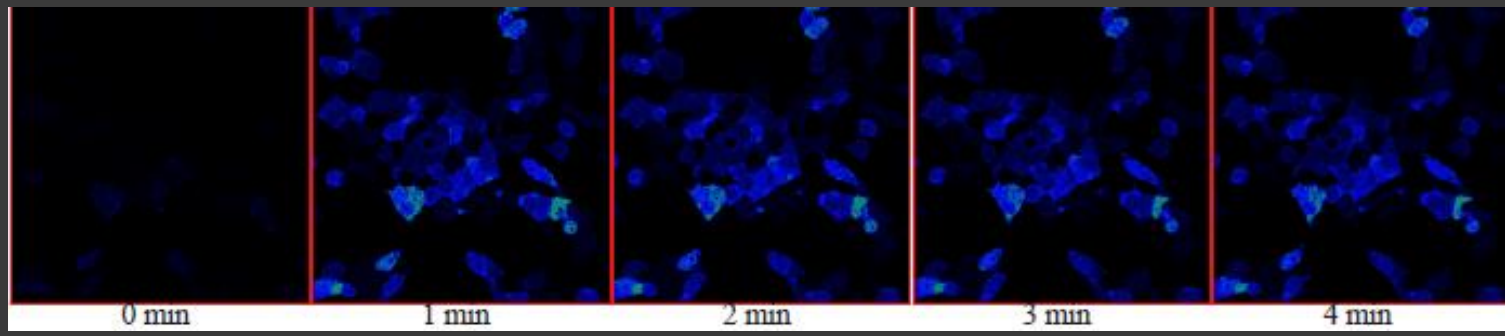
KVANTIFIKACE POVRCHOVÝCH MARKERŮ

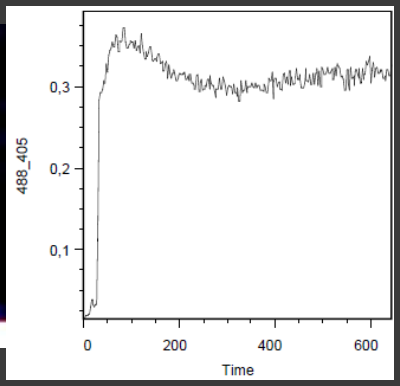
- Hightroughput
- Jednotlivé buňky
- Průchozí světlo + Fluorescence
- Plasticita TROP-2
- Automatizovaná procedura
- Zpracování dat - histogram

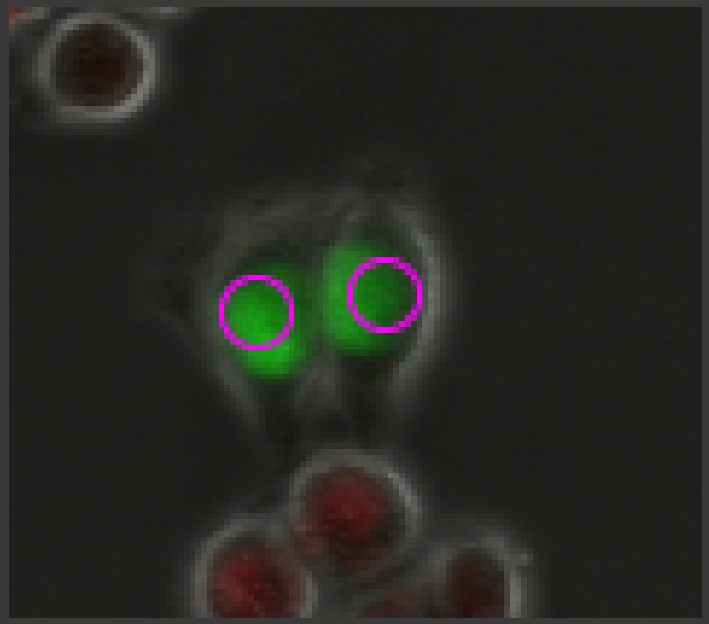


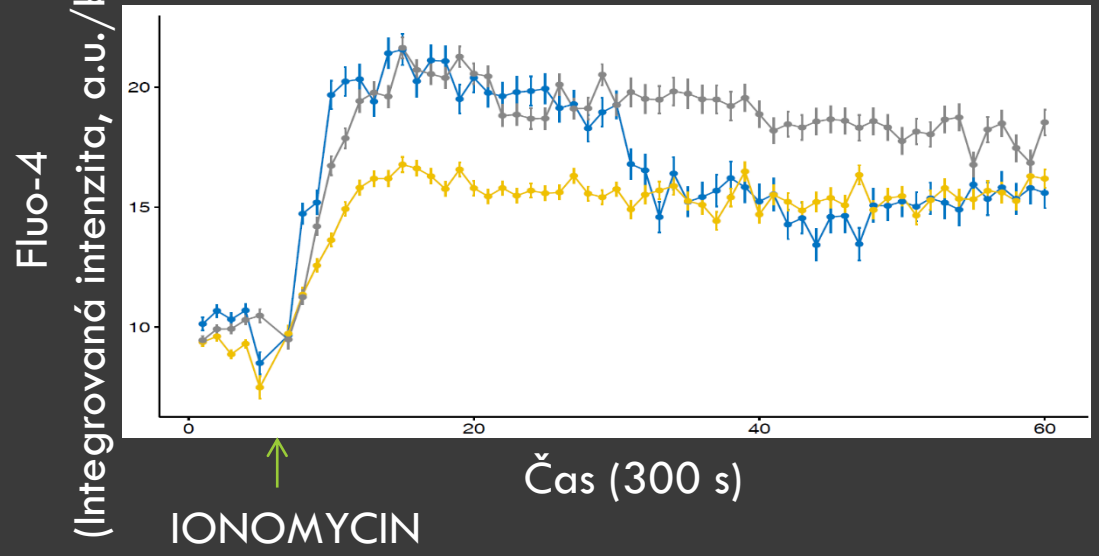


ANALÝZA ŽIVÝCH BUNĚK



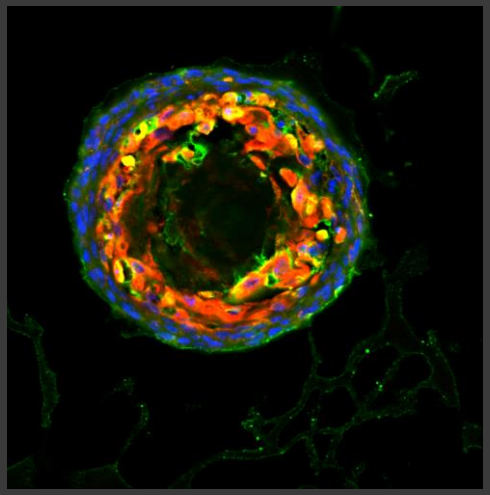


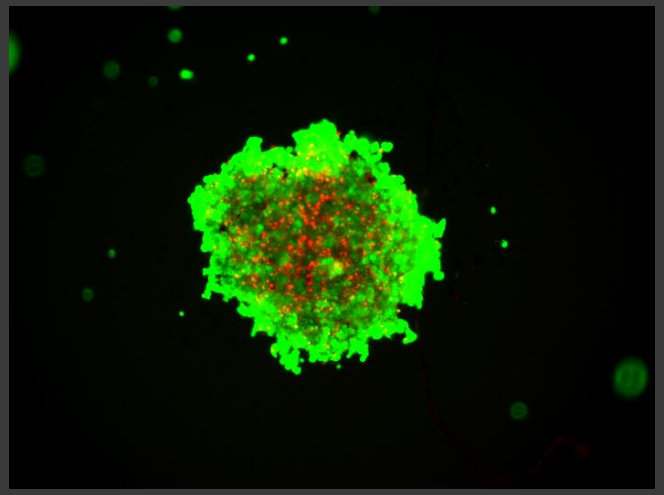


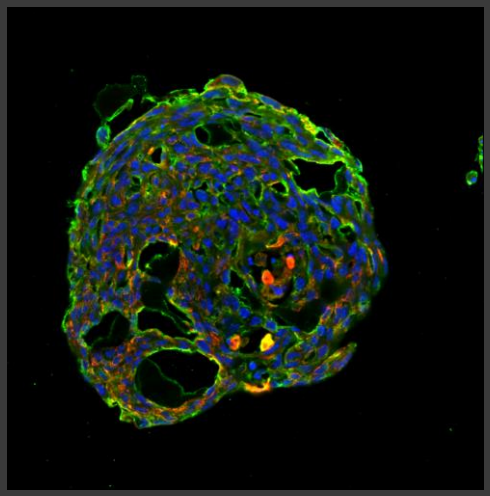


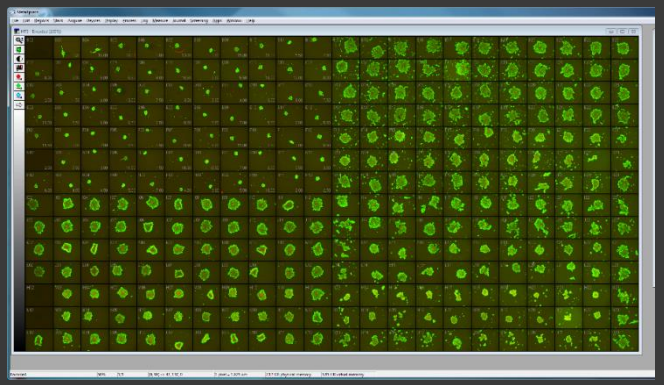
3D ANALÝZY

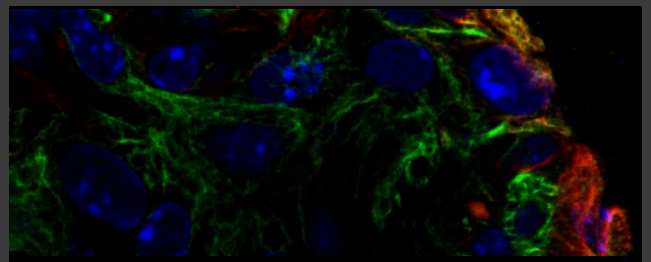
- Kvantifikace objemu
- 3D projekce
- 3D kultivace

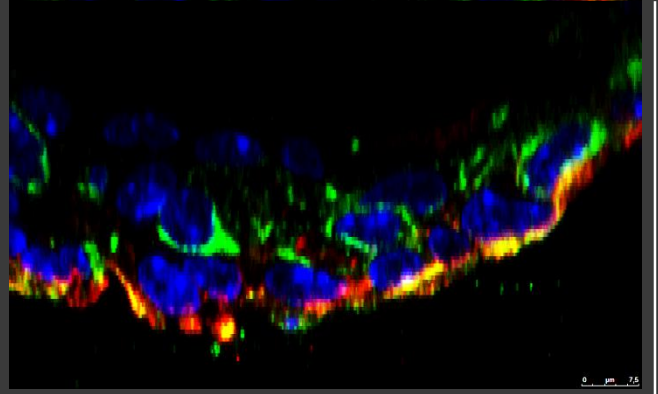


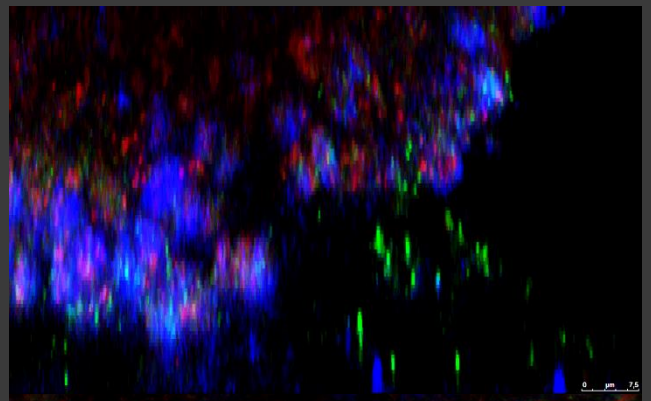


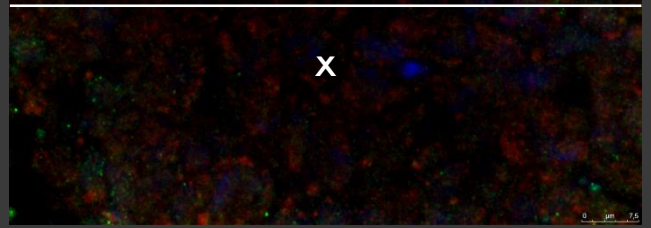










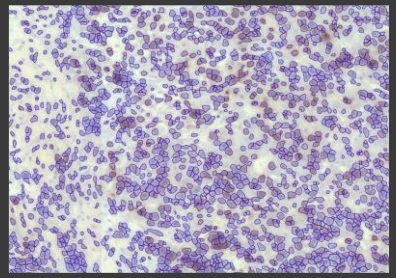


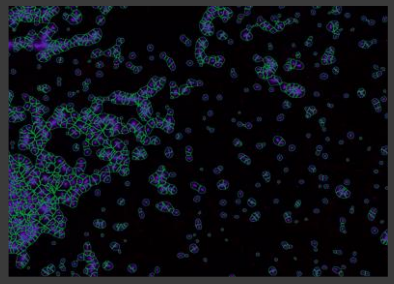
Z

DETEKCE SFEROIDŮ A INVAZIVITY

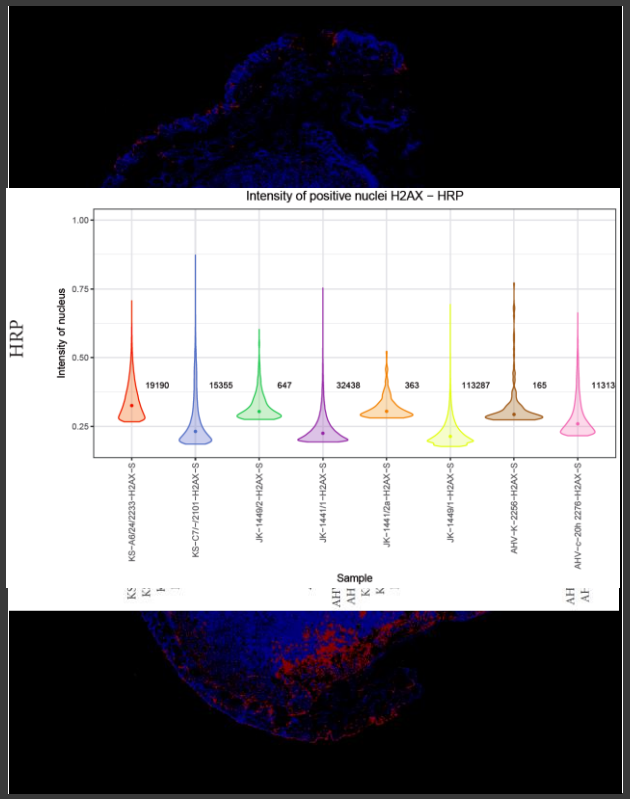
- Hightroughput
- Průchozí světlo
- Detekce sferoidů
- Detekce invadujících buněk
- Plocha

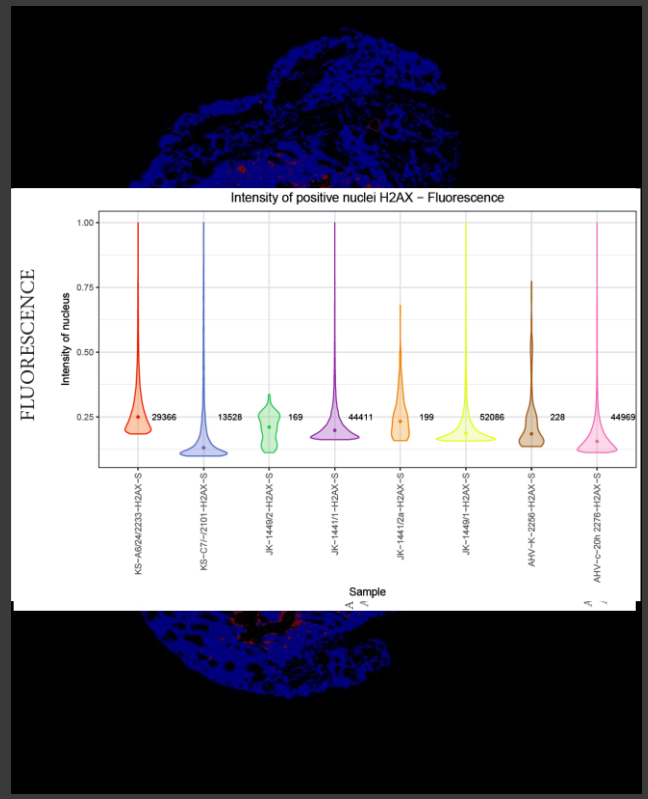
ANALÝZA TKÁNÍ





- Hightroughput
- Barevný obraz
- Fluorescence
- Detekce jader
- Kvantifikace intenzity
- Zpracování dat - R

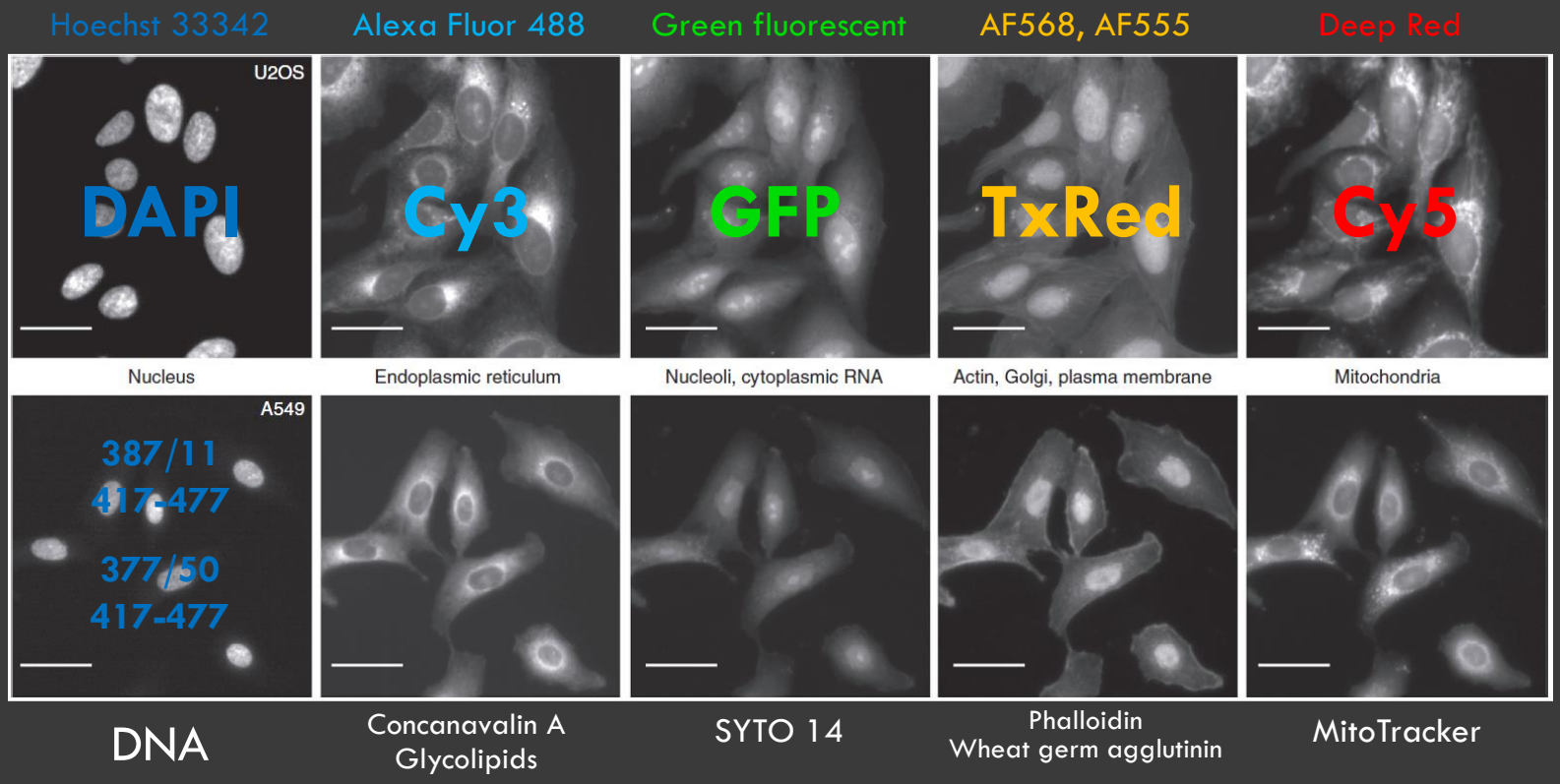




MORFOLOGIE – CELL PAINTING ANALÝZA

- **Nature protokol**
- BRAY, Mark-Anthony, et al. Cell Painting, a high-content image-based assay for morphological profiling using multiplexed fluorescent dyes. Nature protocols, 2016, 11.9: 1757.
- **Vysokokapacitní analýza obrazu pro vytvoření morfologického profilu buněk**
- **6 fluorochromů/protilátek**
- **5 kanálů**
- **8 buněčných kompartment/organel**
- **~1,500 morfologických parametrů**
- **Kultivace & Snímání obrazu = 2 týdny + počítání vlastností & analýza dat = 2 týdny**

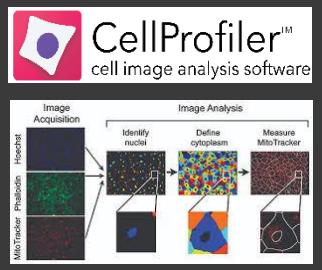
CELL PAINTING – PROTILÁTKY, FLUOROCHROMY



CELL PAINTING - CÍLE

- **Kvantifikace morfologie a rozdílů mezi buněčnými liniemi/klony**
- **Morfologický „otisk“ (profil) buněk**
- **Výběr parametrů s největší odlišností pro jednotlivé linie**

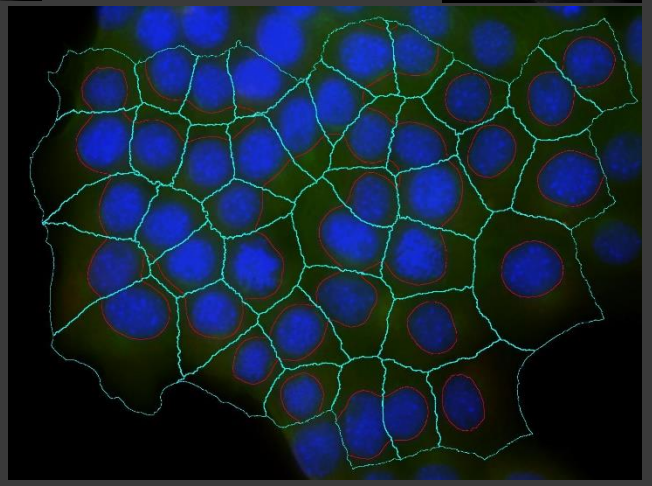
CELL PAINTING - POSTUP

Výsev buněk	Značení	Snímání obrazů	Analýza obrazů	Analýza dat
				
Pátek	Pondělí	Pondělí	Čtvrtek	Další čtvrtek
4 h	3 h	40 h	7 dní	2 h
Speciální deska	Zavedený protokol	Zavedený protokol	3 protokoly	Skript
Manuální, 4jamky/linie = 88 linií, 80% denzita	Poloautomatické	40x objektiv, Adaptivní – 1tis. buněk/jamka, 120 GB	Klastr, Kvalita obrazu, 1785 parametrů	Poloautomatické, heatmapa, PCA, Vi-SNE, Odlišné parametry

CELL PAINTING - VÝSTUPY

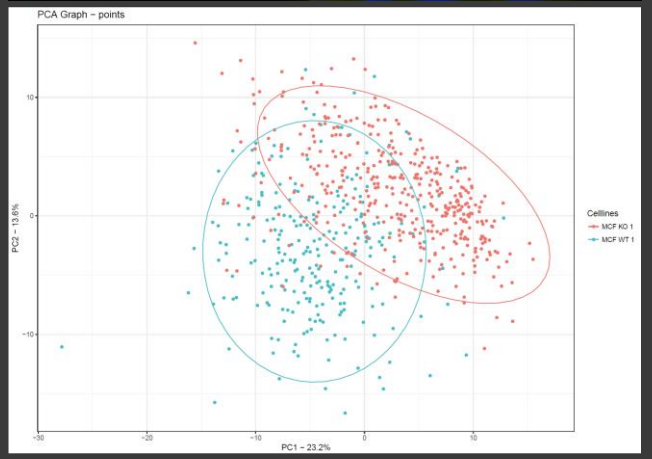
Obrázky

- 16bit a 12bit šedotónové
- Kontrolní obrazy segmentace
- 240GB dat – 1 opakování



Grafy

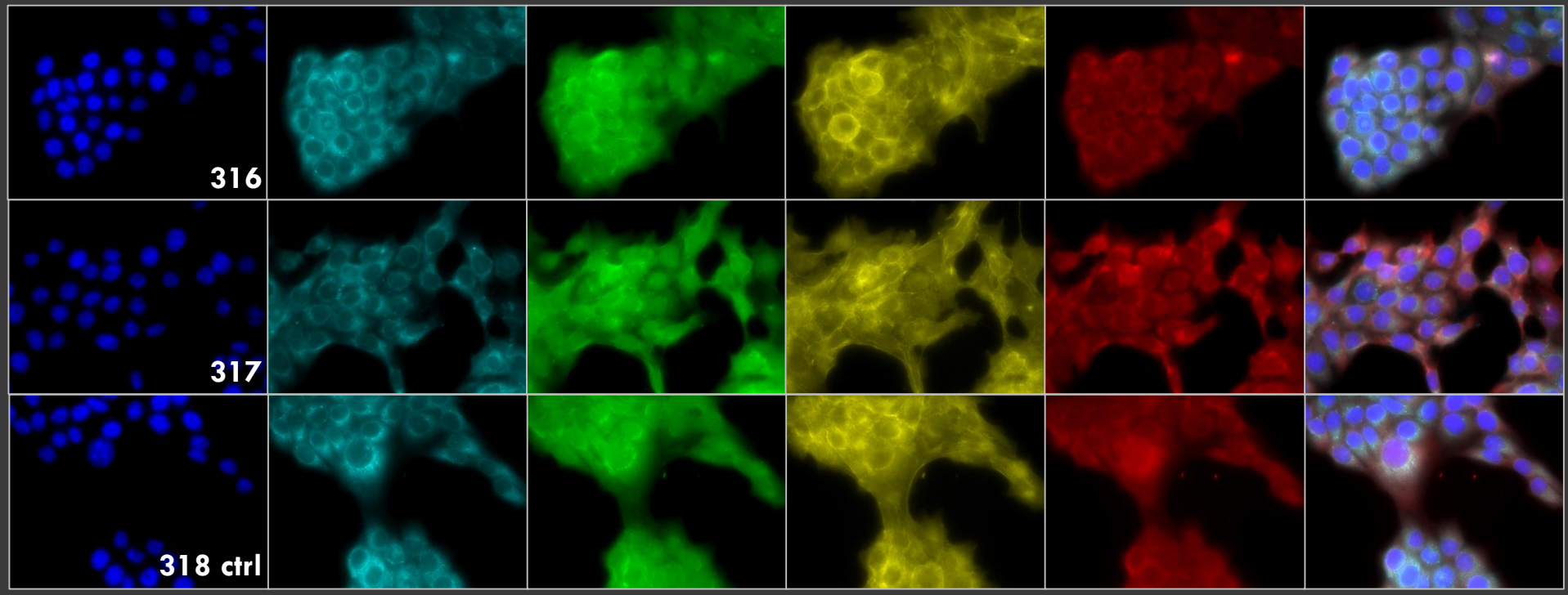
- Heatmapa
- PCA graf
- t-SNE graf



3 Textové soubory & Excel tabulka

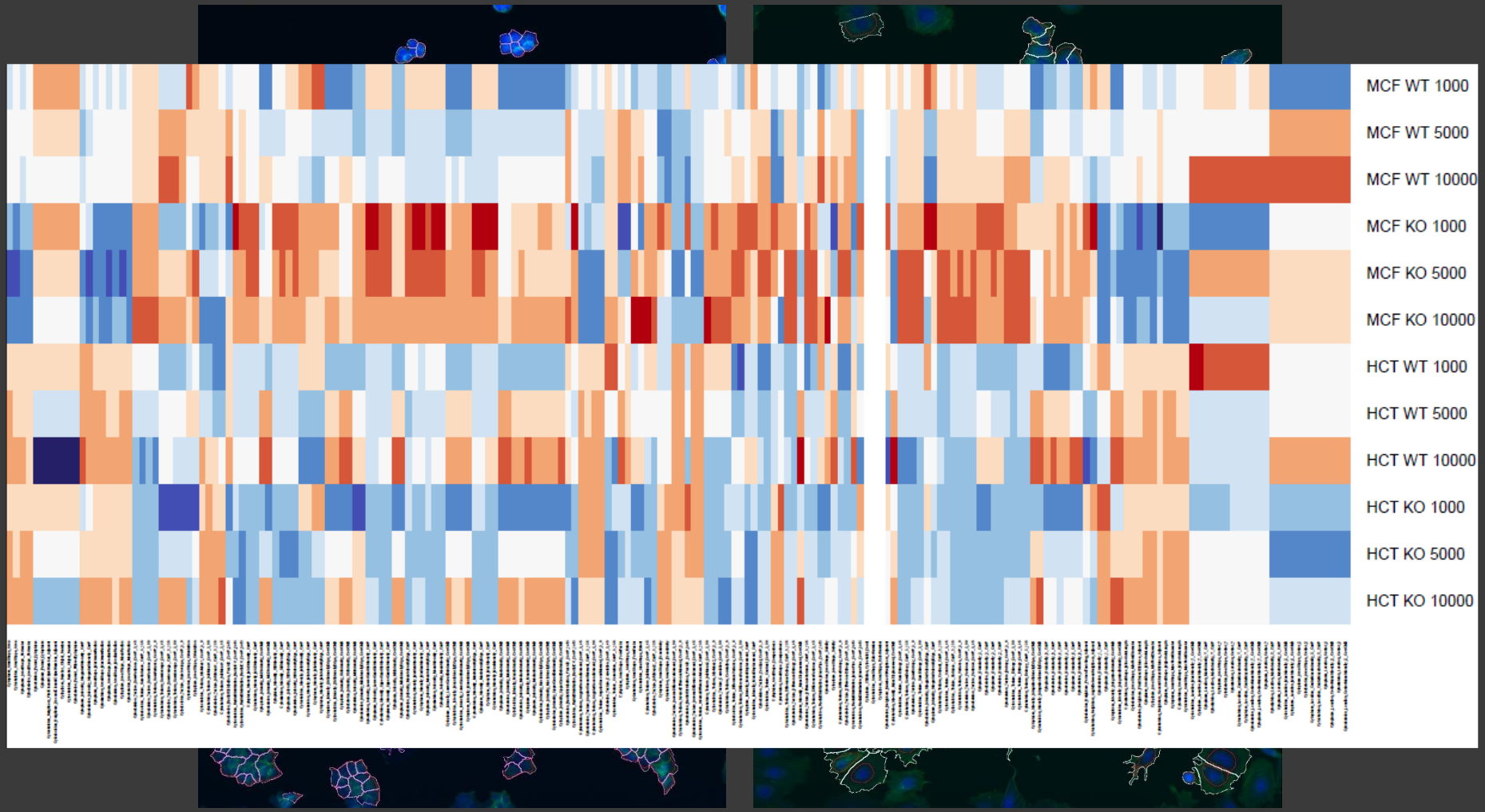
- Jádro, Cytoplazma, Buňka
- přibližně 600 parametrů z každého objektu
- 10 nejvýznamějších parametrů

CELL PAINTING - OBRÁZKY

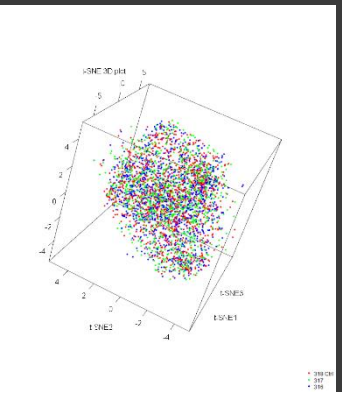


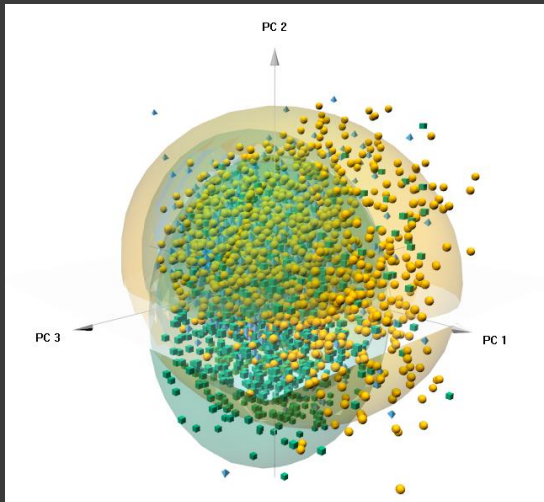
4T1 12B luc2

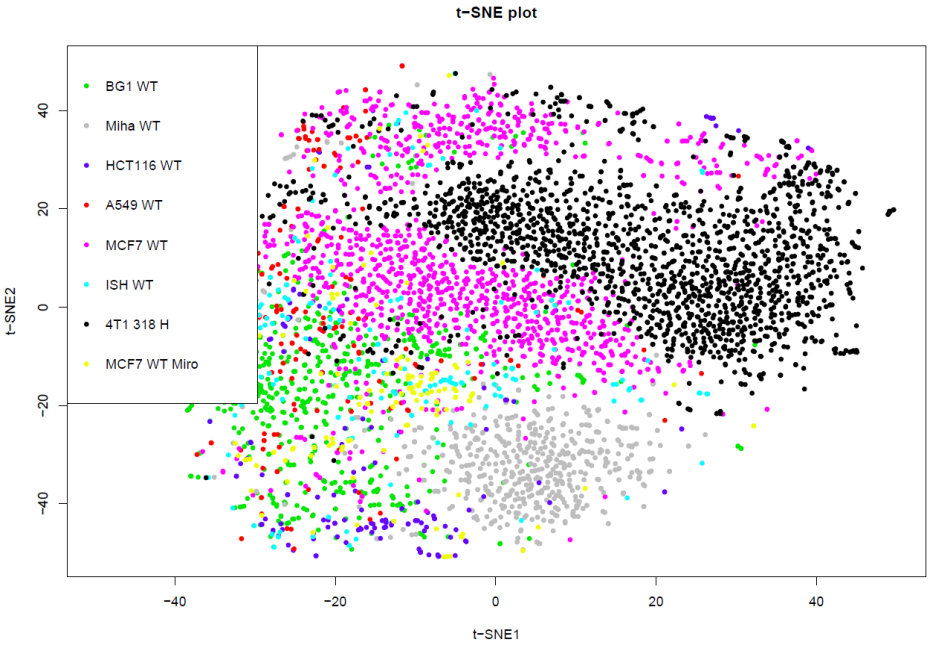
CELL PAINTING - HEATMAPA

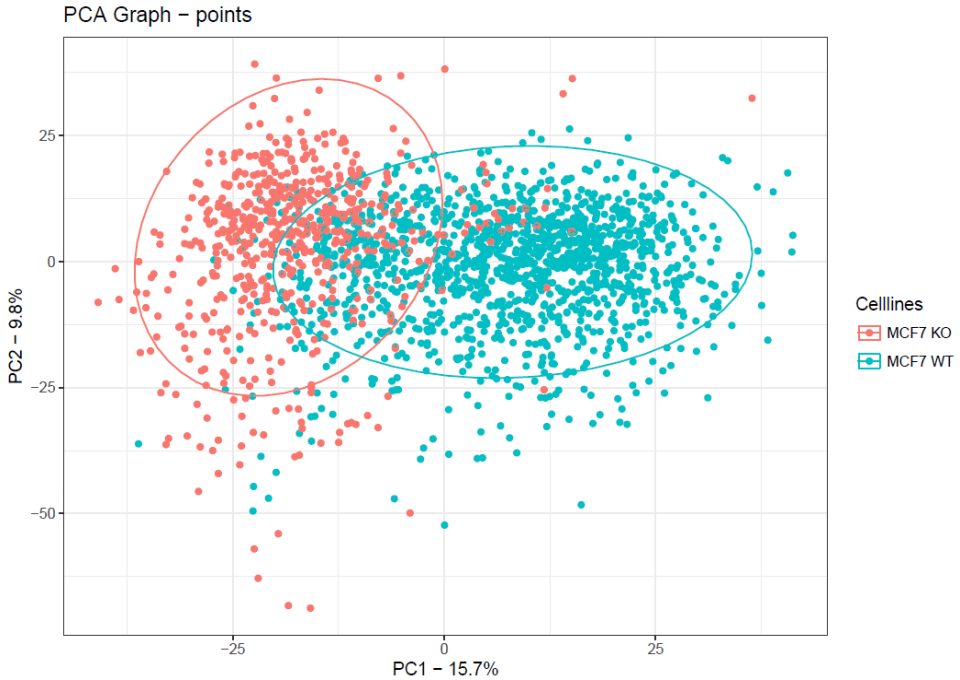


CELL PAINTING – PCA, T-SNE

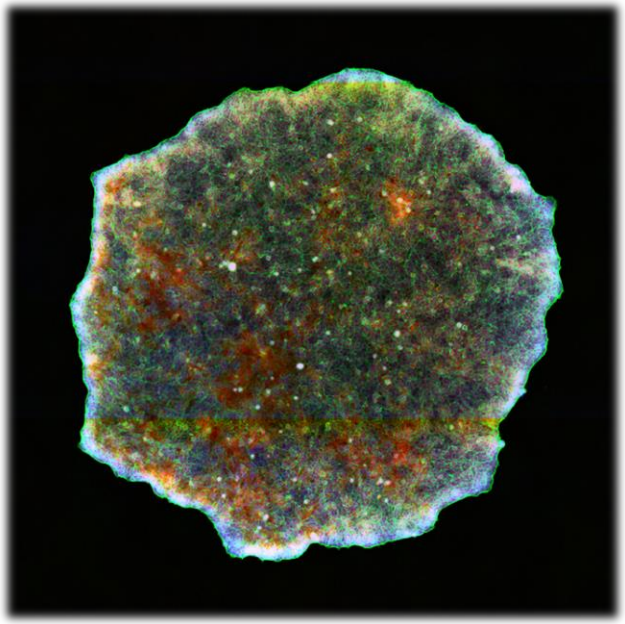








IMAGEJ	http://imagej.nih.gov/ij/
FIJI	http://fiji.sc/
CELLPROFILER	http://www.cellprofiler.org/
ILASTIK	http://ilastik.org/



IBP Institute of Biophysics

FNUSA ICRC

ICRC–ERA–HUMAN BRIDGE

Co-funded by the 7th Framework Programme of the European Union

DĚKUJI ZA POZORNOST

27.11.2018, 4.12.2018

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