GPU-accelerated real-time image analysis: key to smart microscopy

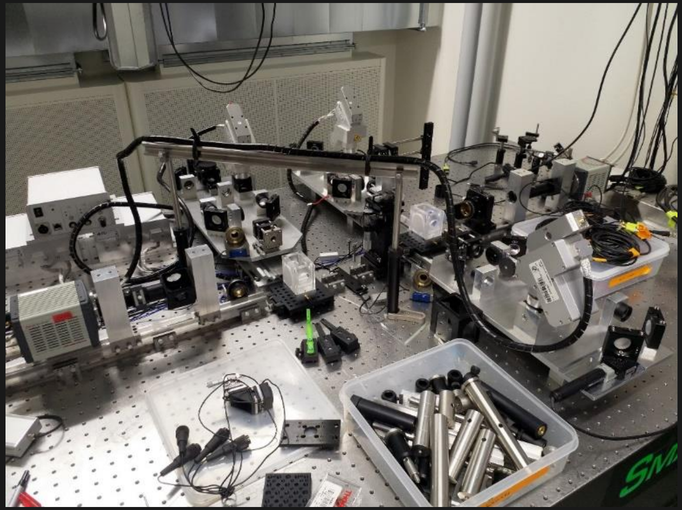
Robert Haase, Daniela Vorkel, Akanksha Jain, Nicola Maghelli, Pavel Tomancak, Eugene W. Myers

Myers lab, MPI CBG / CSBD Dresden

#QBI2020

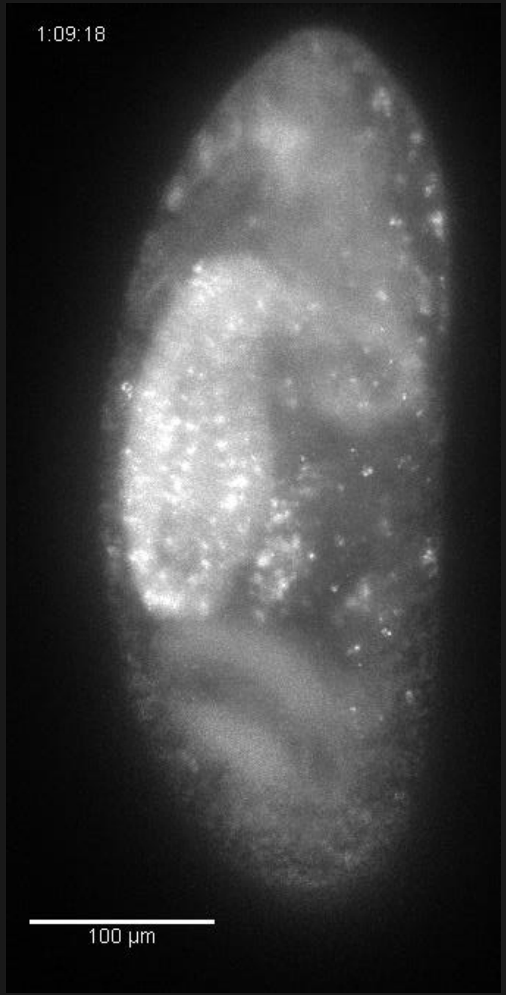
Introduction: Gene Myers lab – Smart Microscopy

- 5 Microscopes
  - Spinning disc confocal
  - Meso-scope
  - 3 light sheet microscopes
- Closest collaborators
  - Advanced Imaging Facility @ MPI CBG
  - Tomancak lab @ MPI CBG
  - Jug lab @ CSBD / MPI CBG
  - Royer lab @ CZ Biohub



Fast long-term live imaging

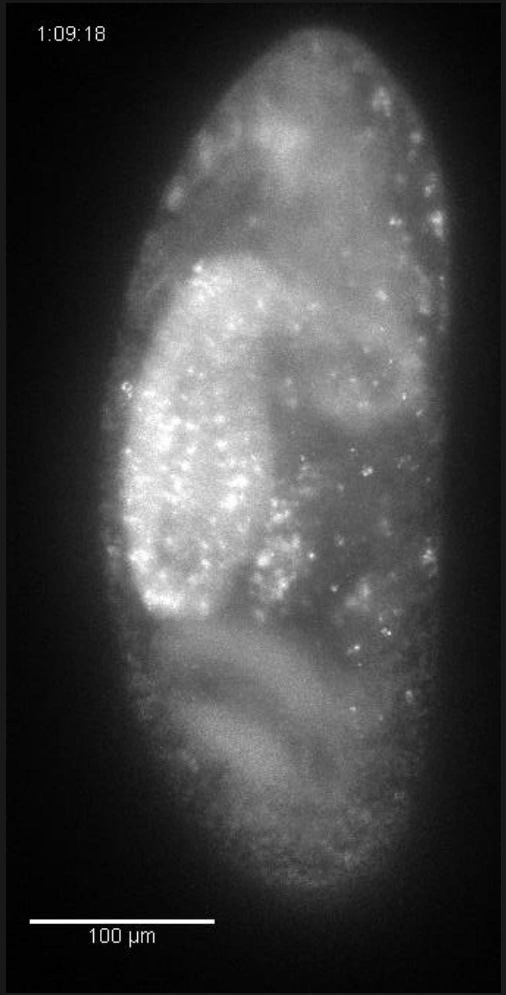
- Imaging fast



Hatching Drosophila larva @ 20 fpm

Fast long-term live imaging

- Imaging fast ~~and~~ long-term



Hatching Drosophila larva @ 20 fpm

Imaging 1 week
with 20 fpm
200 MB each
================
200000 frames = 40 TB

Tribolium embryo development:
1 week, 3506 frames

Smart Microscopy

Dear microscope, we just put a *Tribolium castaneum* embryo in your chamber. Could you please

- image ventral furrow formation at increased frame rate?

Smart Microscopy

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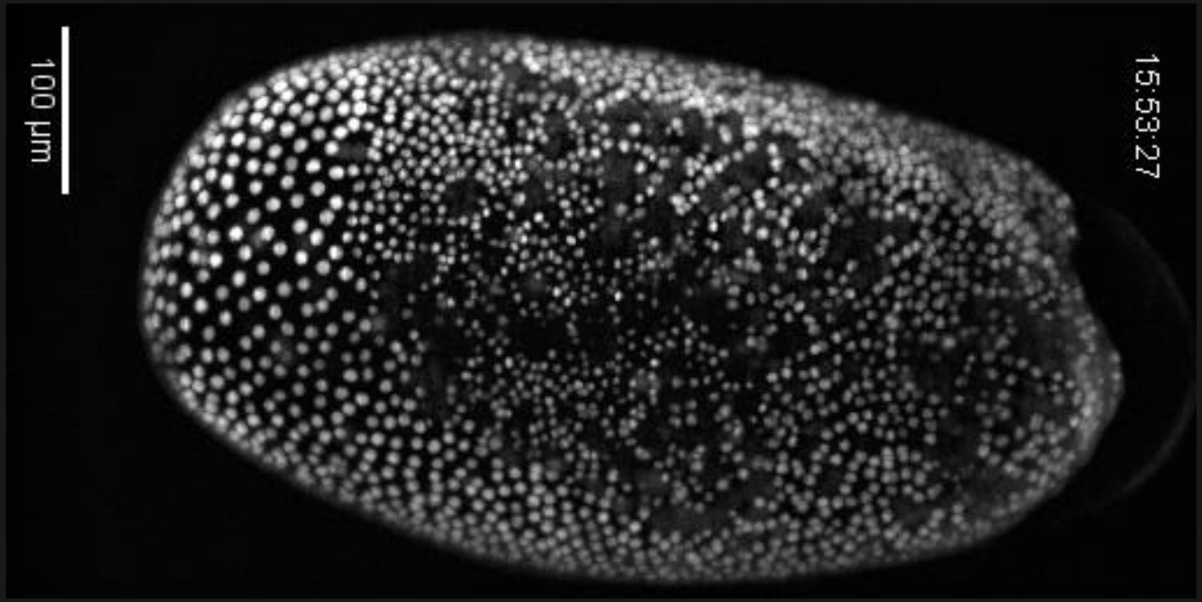
- image ventral furrow formation at increased frame rate?

Sure! I increased frame rate after 17 h 50 min.

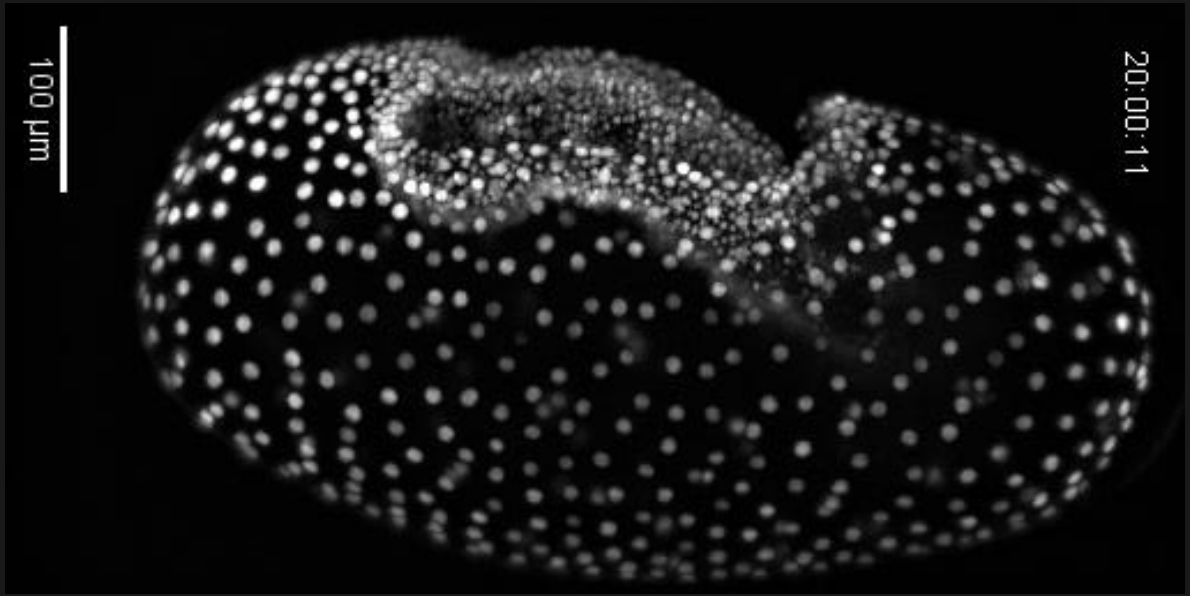


Smart Microscopy

Dear microscope, we just put a *Tribolium castaneum* embryo in your chamber. Could you please

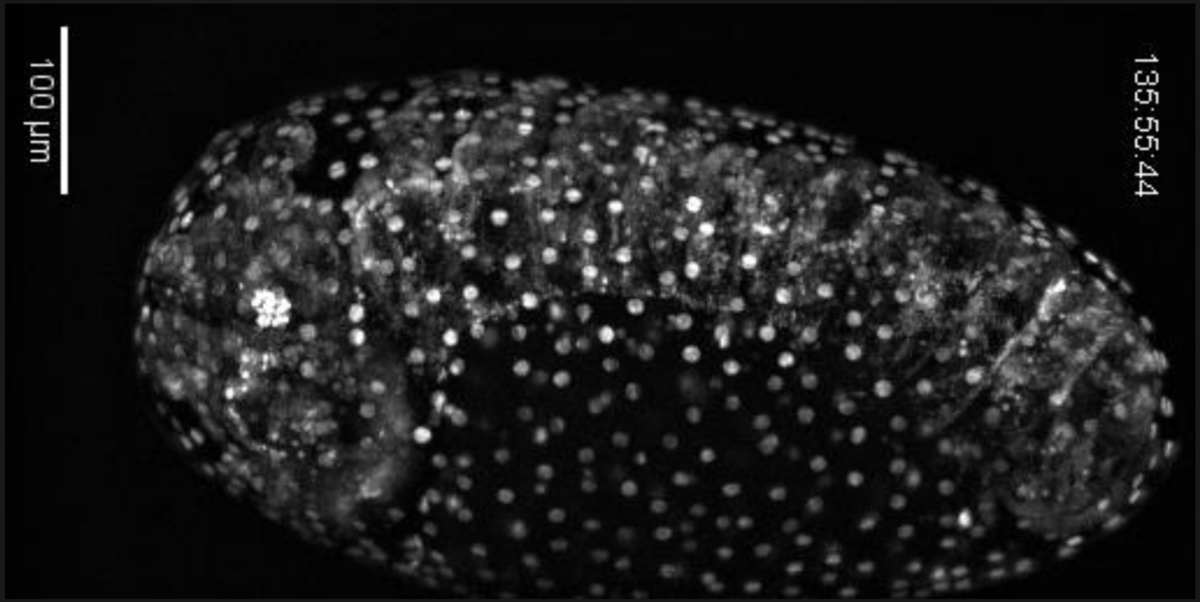
- image ventral furrow formation at increased frame rate?

Sure! I increased frame rate at 17:50.



- take a time lapse of serosa rupture?

Sure! Serosa rupture happened after 139 h 35 min

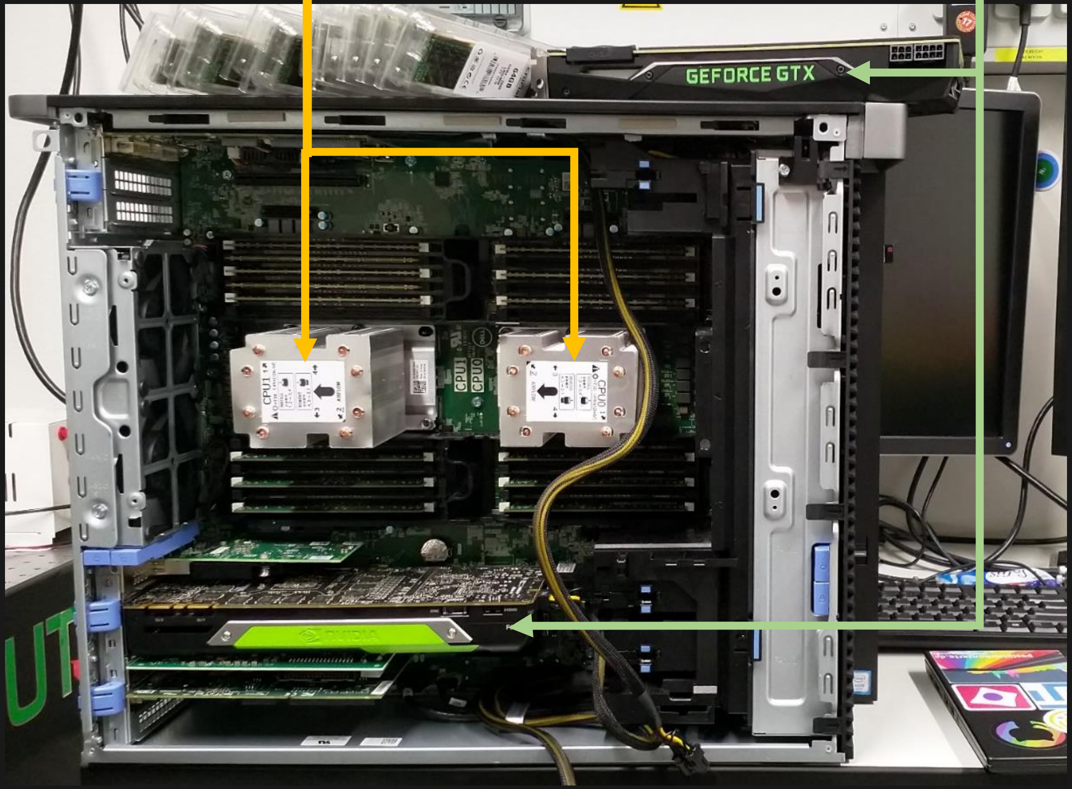


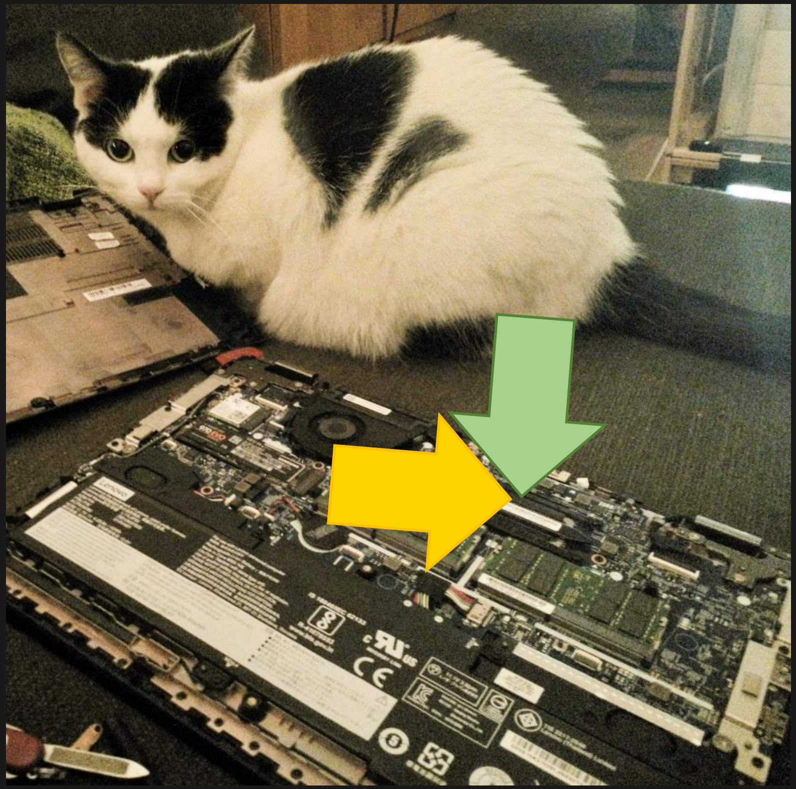
GPU-accelerated image processing

- Typical computers contain Graphics Processing Units

Central Processing Unit (CPU)

Graphics Processing Unit (GPU)





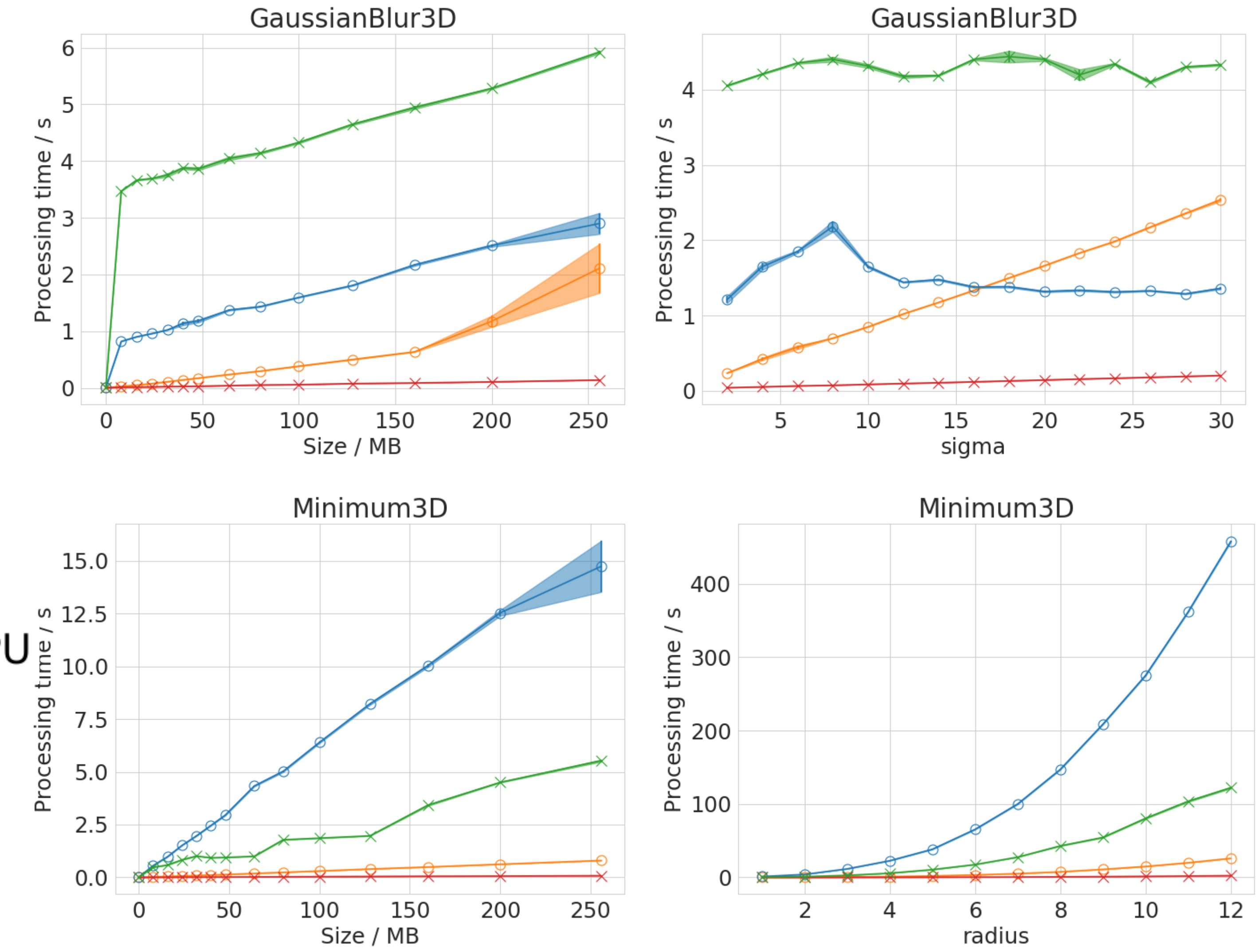
Most laptops contain *integrated* GPUs

Alternative: *external* GPUs

GPU-accelerated image processing

- … depends on operation, image size, parameters, hardware, ….

vs.



Workstation CPU
2x Intel Xeon Silver 4110

Workstation GPU
Nvidia Quadro P6000

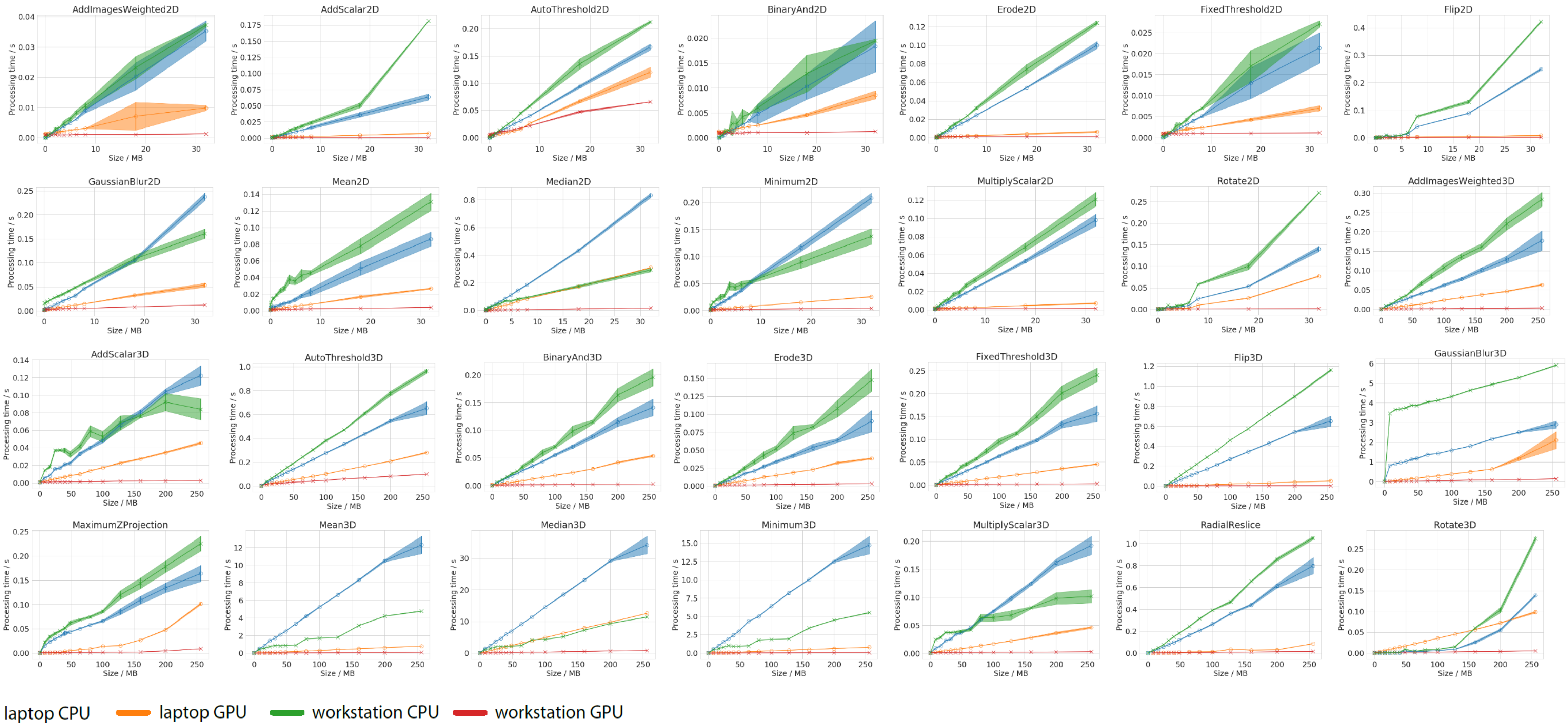
Laptop CPU
Intel Core i7-8650U

Laptop GPU
Intel UHD 620 GPU

Haase et al Nat Methods (2019)

GPU-accelerated image processing

- … depends on operation, image size, parameters, hardware, ….



GPU-accelerated image processing

- 8 MB (2D)
- 64 MB (3D)

Speedup compared to Laptop CPU

	Laptop GPU	Workstation GPU
AddImagesWeighted2D	3	8
AddScalar2D	7	14
AutoThreshold2D	2	2
BinaryAnd2D	2	4
Erode2D	11	20
FixedThreshold2D	2	5
Flip2D	16	37
GaussianBlur2D	3	9
Mean2D	3	10
Median2D	2	35
Minimum2D	7	22
MultiplyScalar2D	10	21
Rotate2D	3	22
AddImagesWeighted3D	3	26
AddScalar3D	3	23
AutoThreshold3D	3	5
BinaryAnd3D	3	24
Erode3D	2	13
FixedThreshold3D	4	30
Flip3D	15	119
GaussianBlur3D	6	35
MaximumZProjection	7	46
Mean3D	18	150
Median3D	3	43
Minimum3D	23	188
MultiplyScalar3D	4	28
RadialReslice	14	42
Rotate3D	0.1	2

Haase et al Nat Methods (2019)

Event driven smart microscopy

- Spot detection for developmental stage estimation

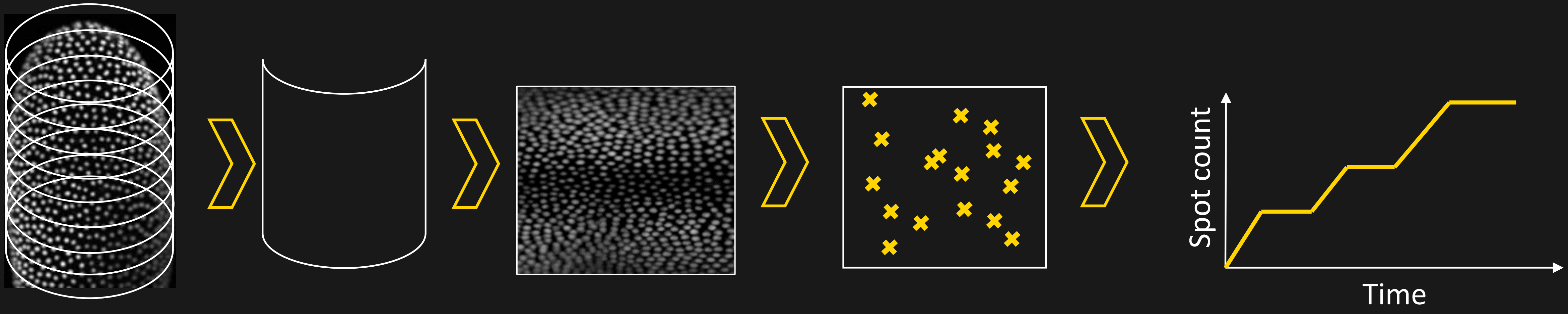


Image stack — Cylinder maximum projection — Spot detection — Spot count over time

Event driven smart microscopy

- Spot detection for developmental stage estimation

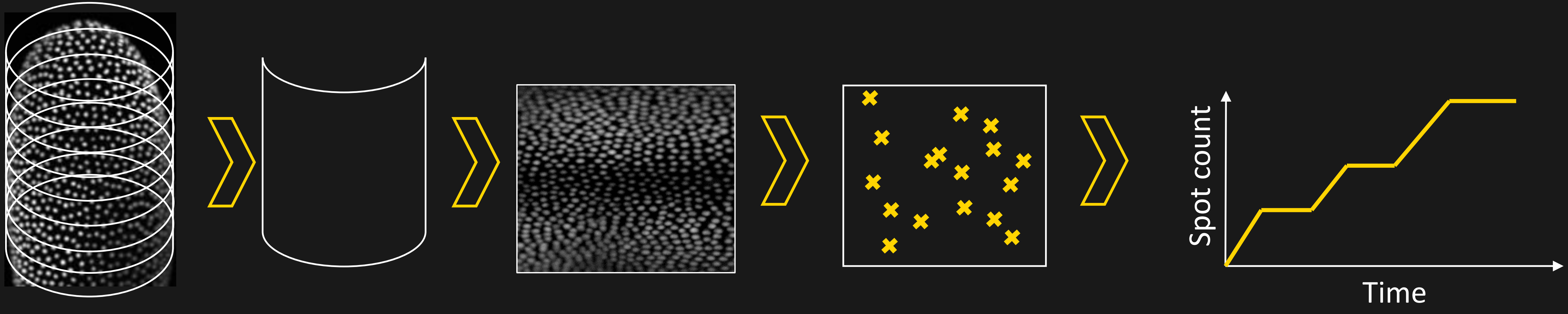
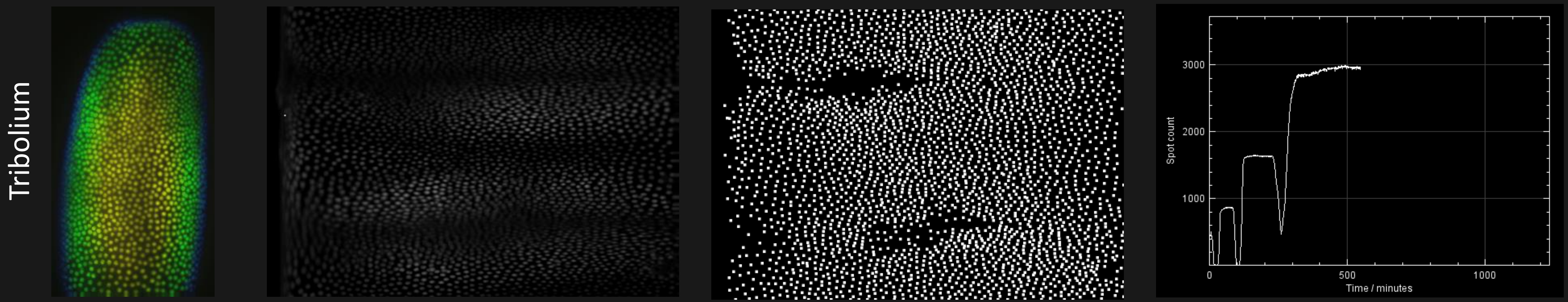


Image stack

Cylinder maximum projection

Spot detection

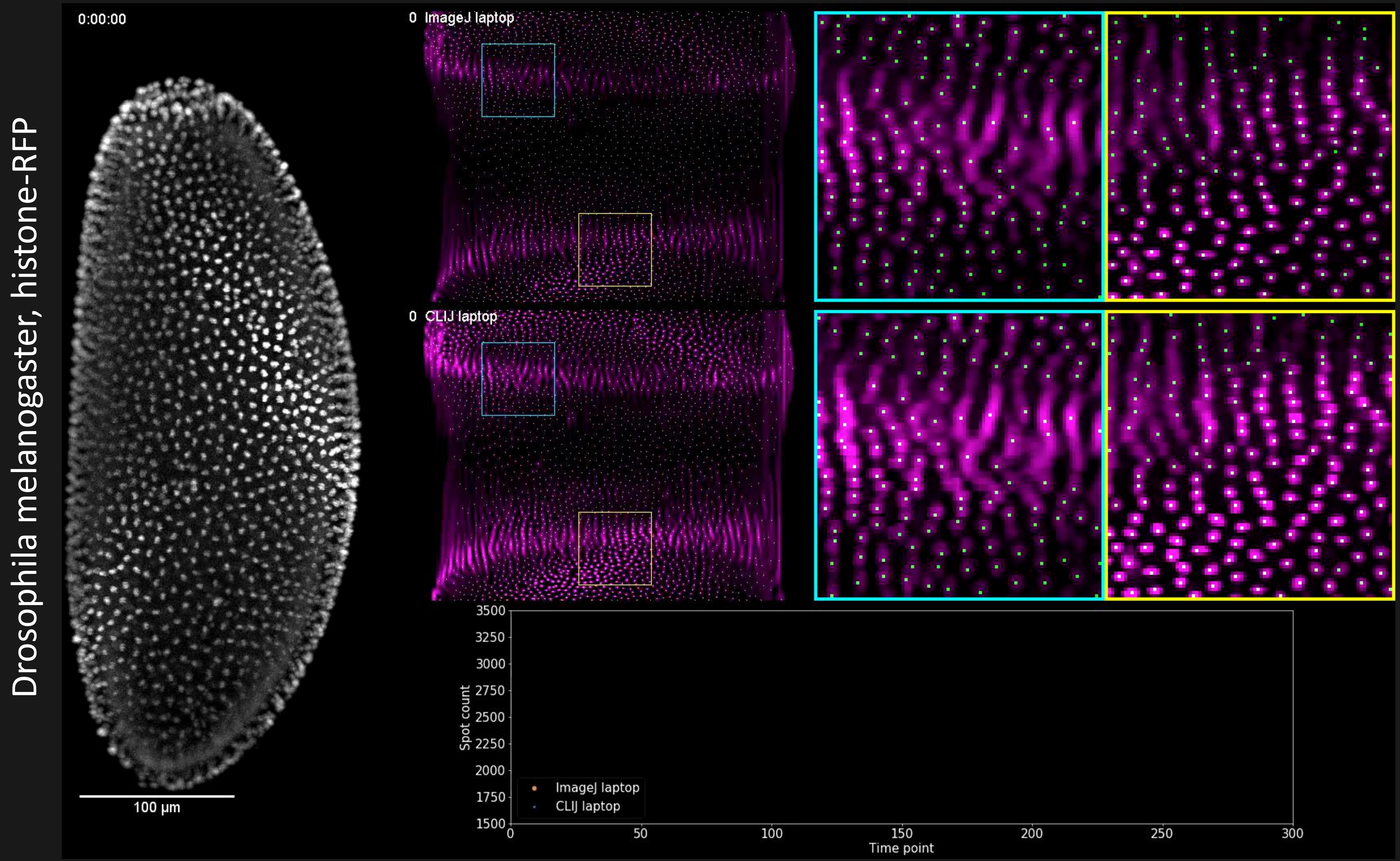
Spot count over time



@haesleinhuepf https://clij.github.io/

Real-time image processing

- Counting spots in 300 frames of light sheet data (including I/O)



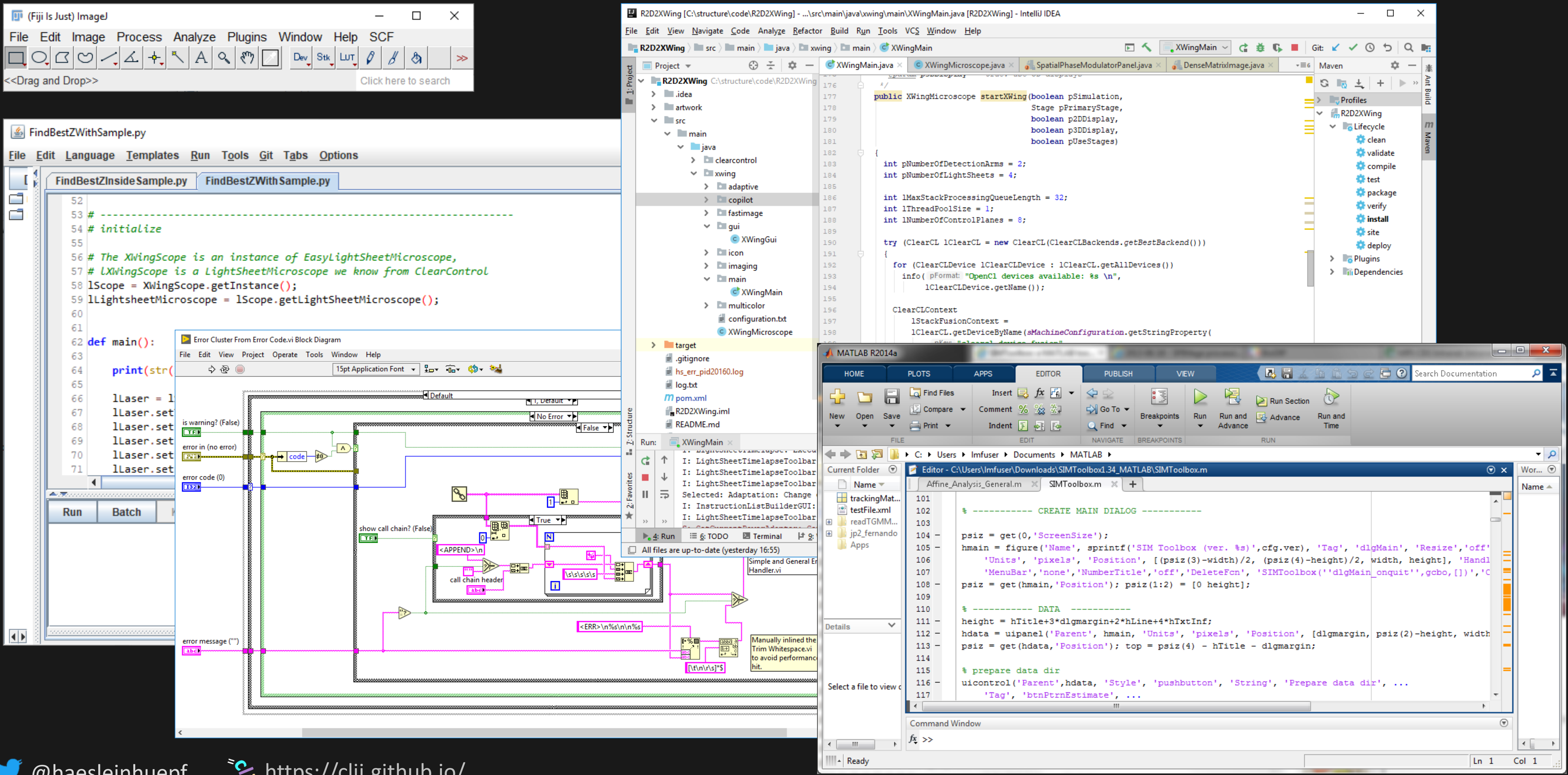
ImageJ on CPU (laptop)
33 seconds per frame
2:44 h (timelapse)

ImageJ using the GPU (laptop)
2.2 seconds per frame
11 min (timelapse)

ImageJ using a dedicated GPU (workstation)
1 second per frame
5 min (timelapse)

Haase et al Nat Methods (2019)

Smart microscopy: in practice

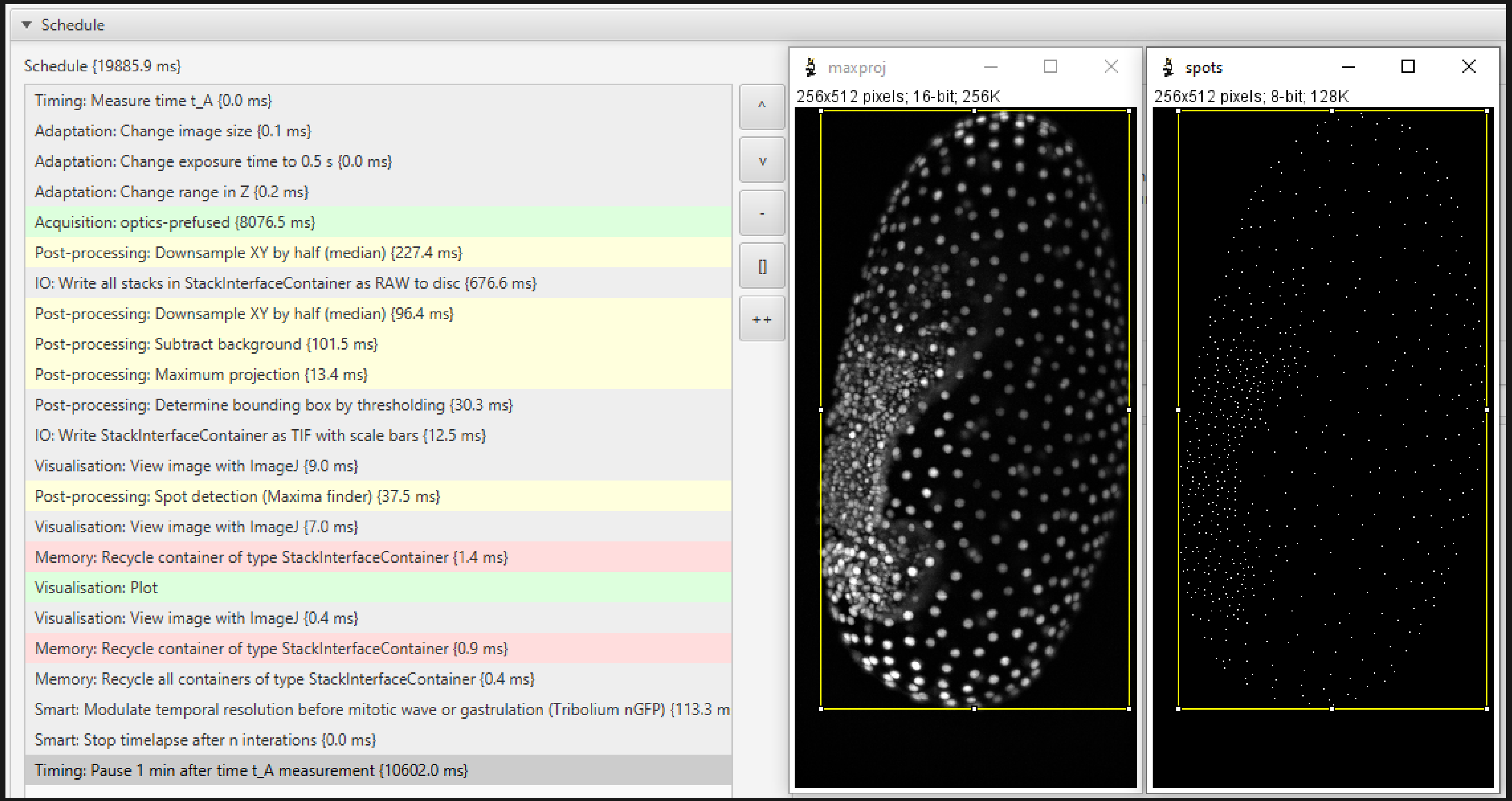


Smart microscopy for the end user

Acquisition + I/O: 9 s

Image analysis: 0.7 s

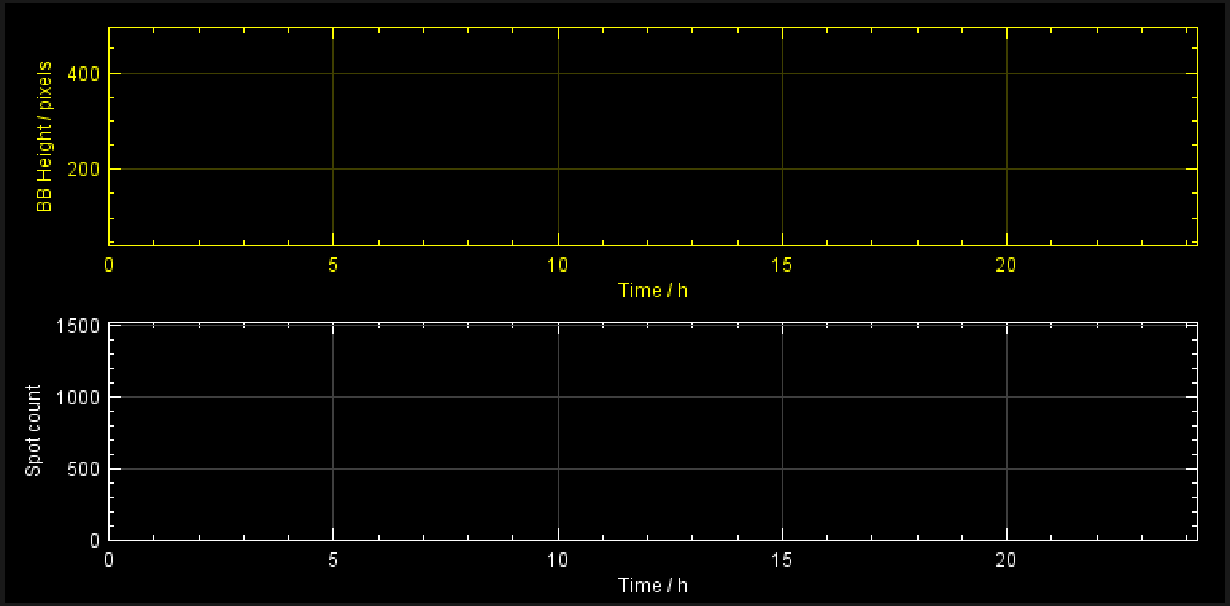
- Downsampling
- Background subtraction
- Maximum projection
- Determine bounding box
- Spot detection



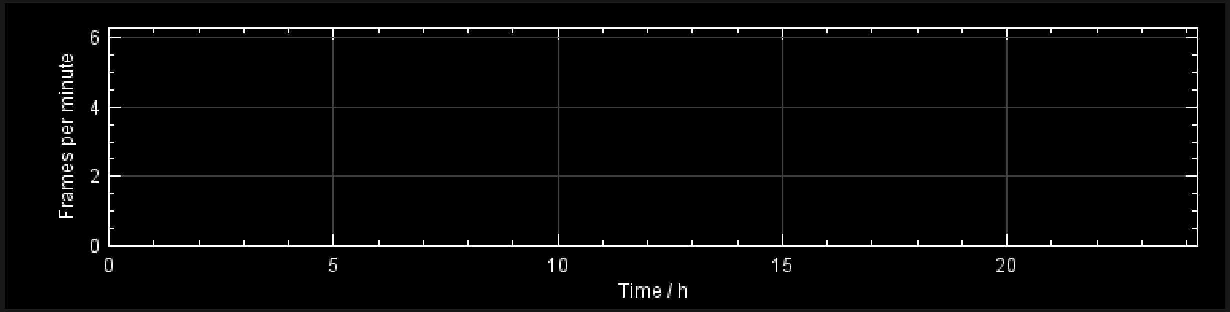
Modulating temporal resolution

Increasing temporal detail when it matters.

- Measurements



- Frame rate



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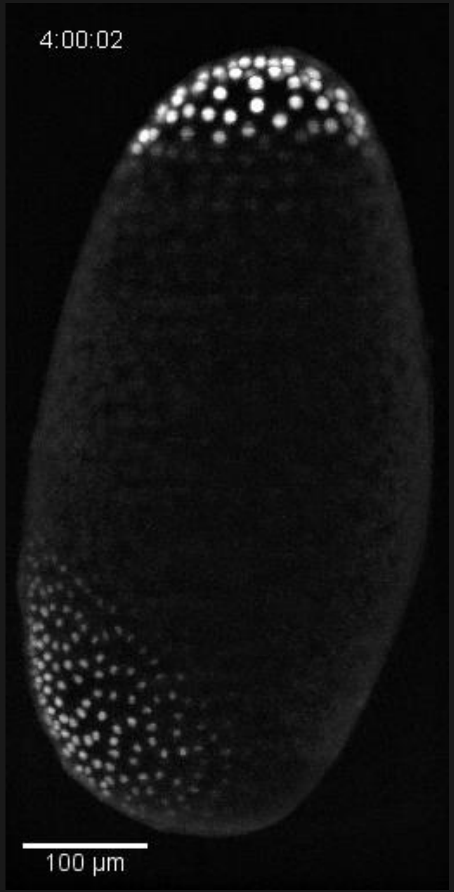
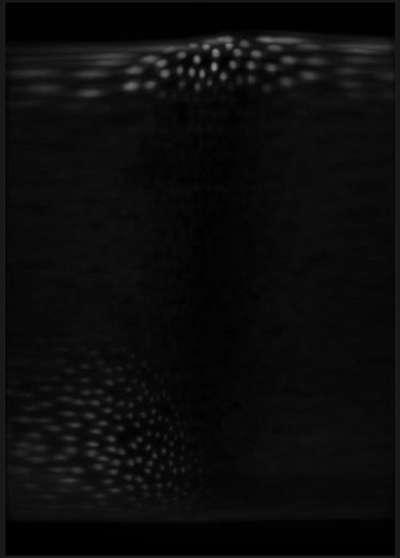
Outlook: Complex image analysis enabled by GPU-acceleration

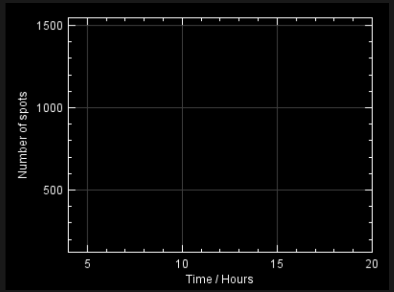
- Algorithmic complexity is the challenge towards real-time analysis

Complexity



nuclei-GFP,
Background subtracted





Cylinder-max-projection
+ spot count

Outlook: Complex image analysis enabled by GPU-acceleration

- Algorithmic complexity is the challenge towards real-time analysis

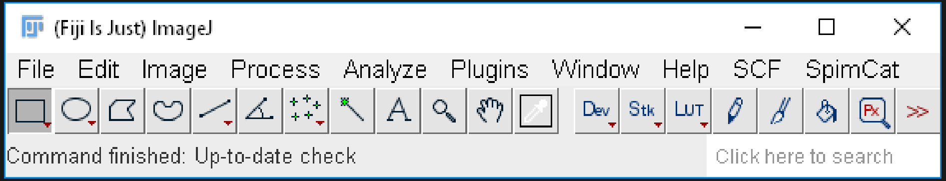
Complexity

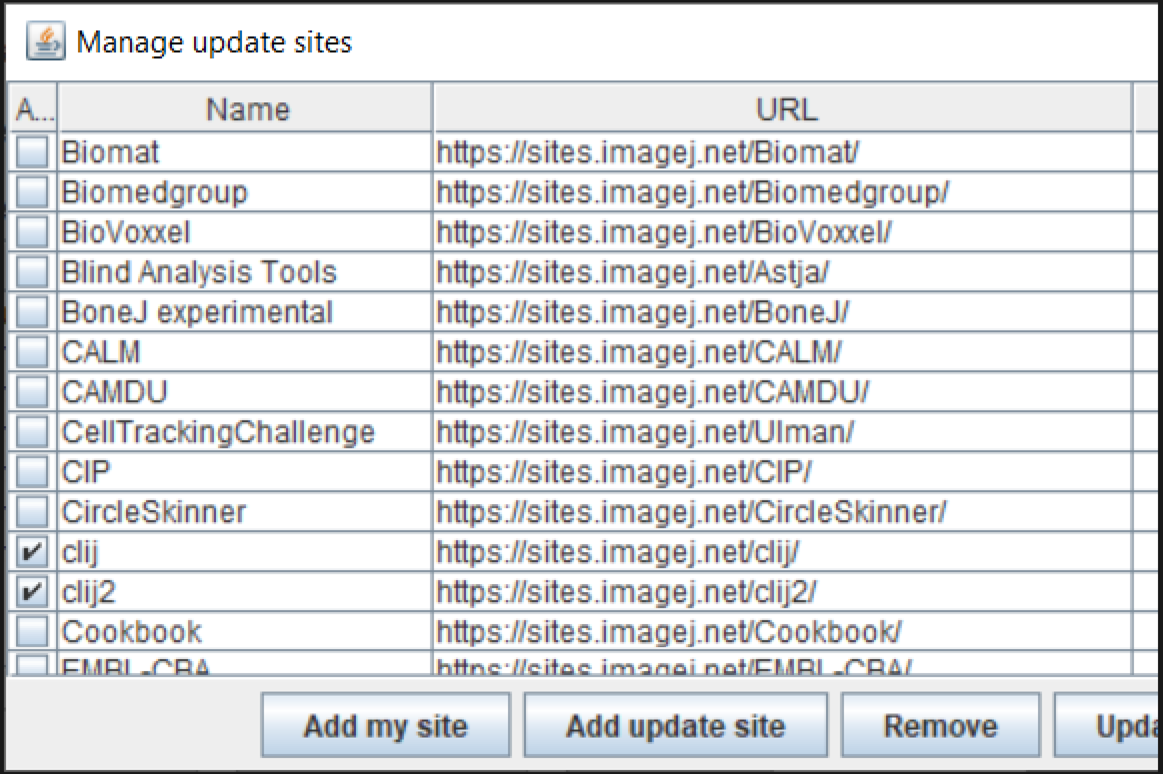
nuclei-GFP, Background subtracted | Spot detection (3D) | Theoretical membranes (pseudo Voronoi map) | Neighbor mesh | Average distance to neighbors

0 µm 35

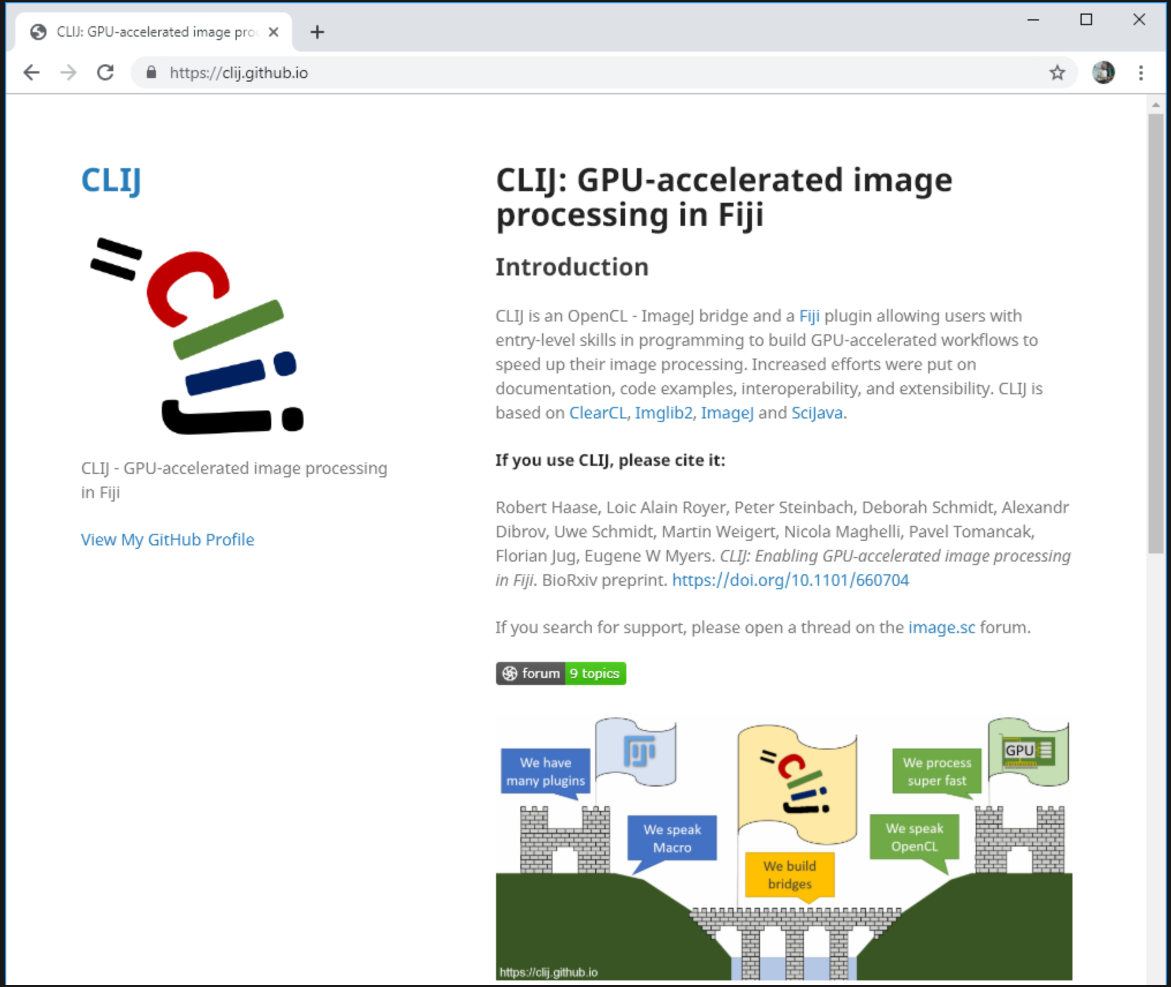
GPU-accelerated image processing for everyone

- Just activate/enter the CLIJ update site(s)



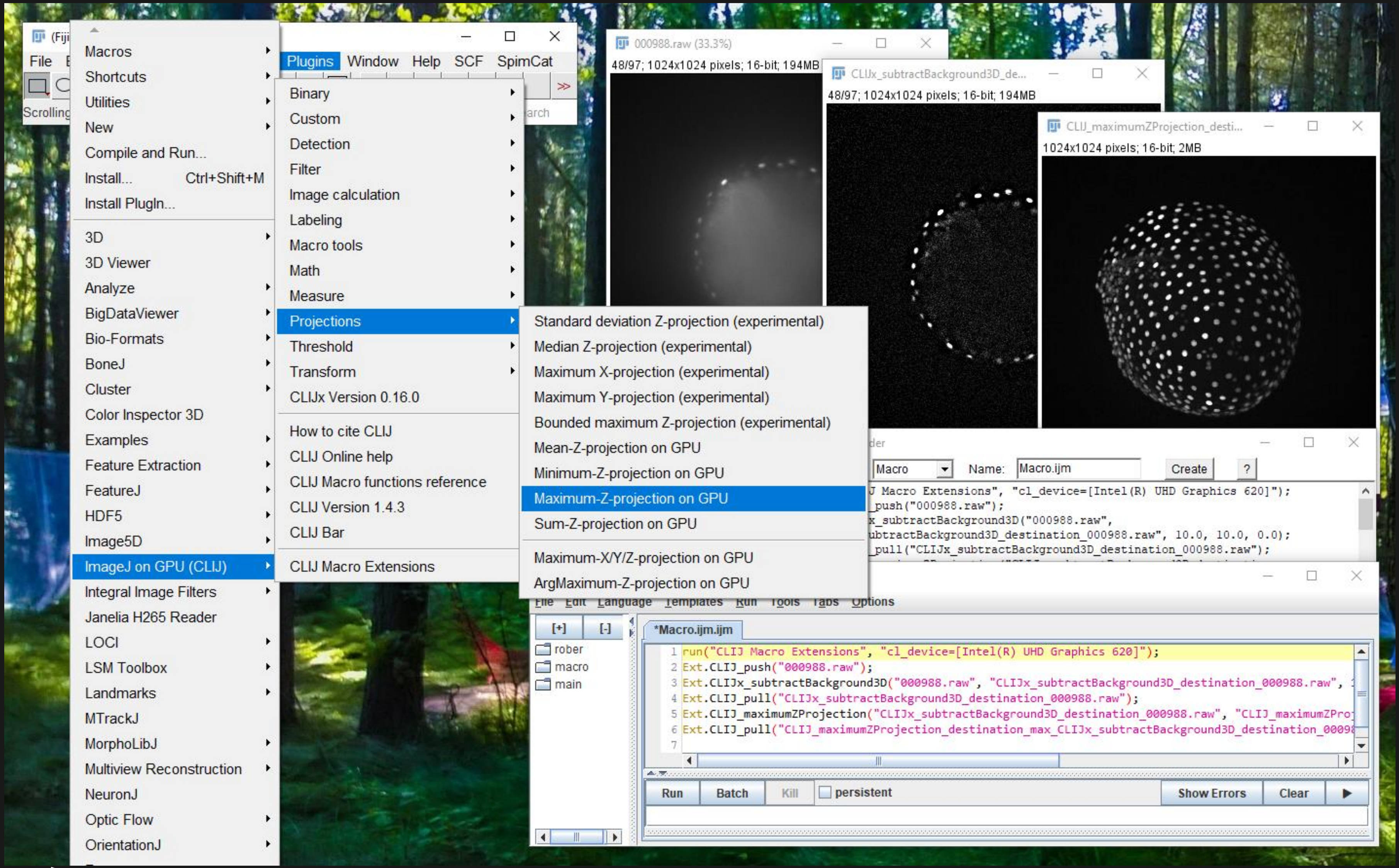


- Online documentation



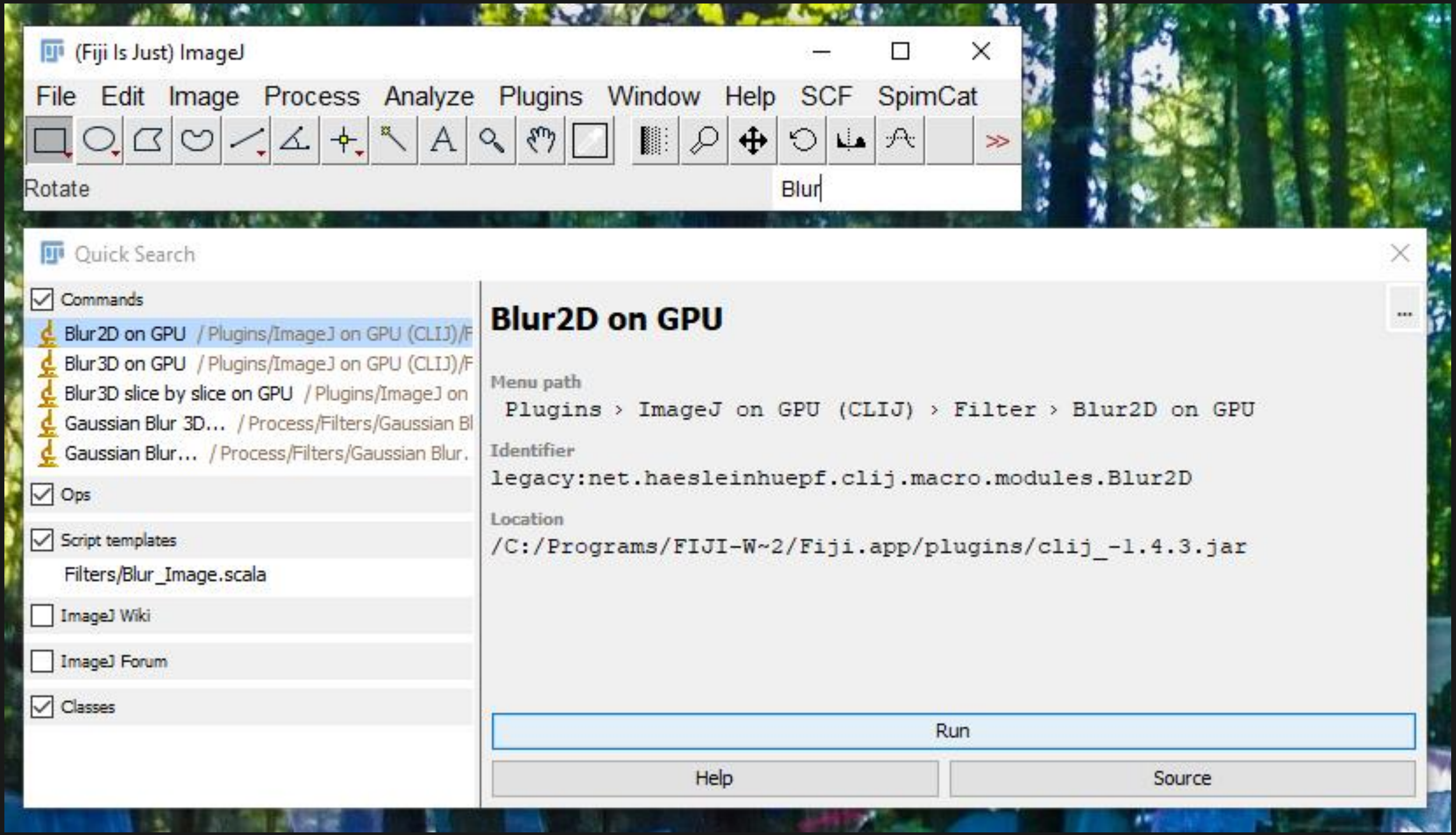
GPU-accelerated image processing for everyone

- The ImageJ macro recorder does the main part of the job!



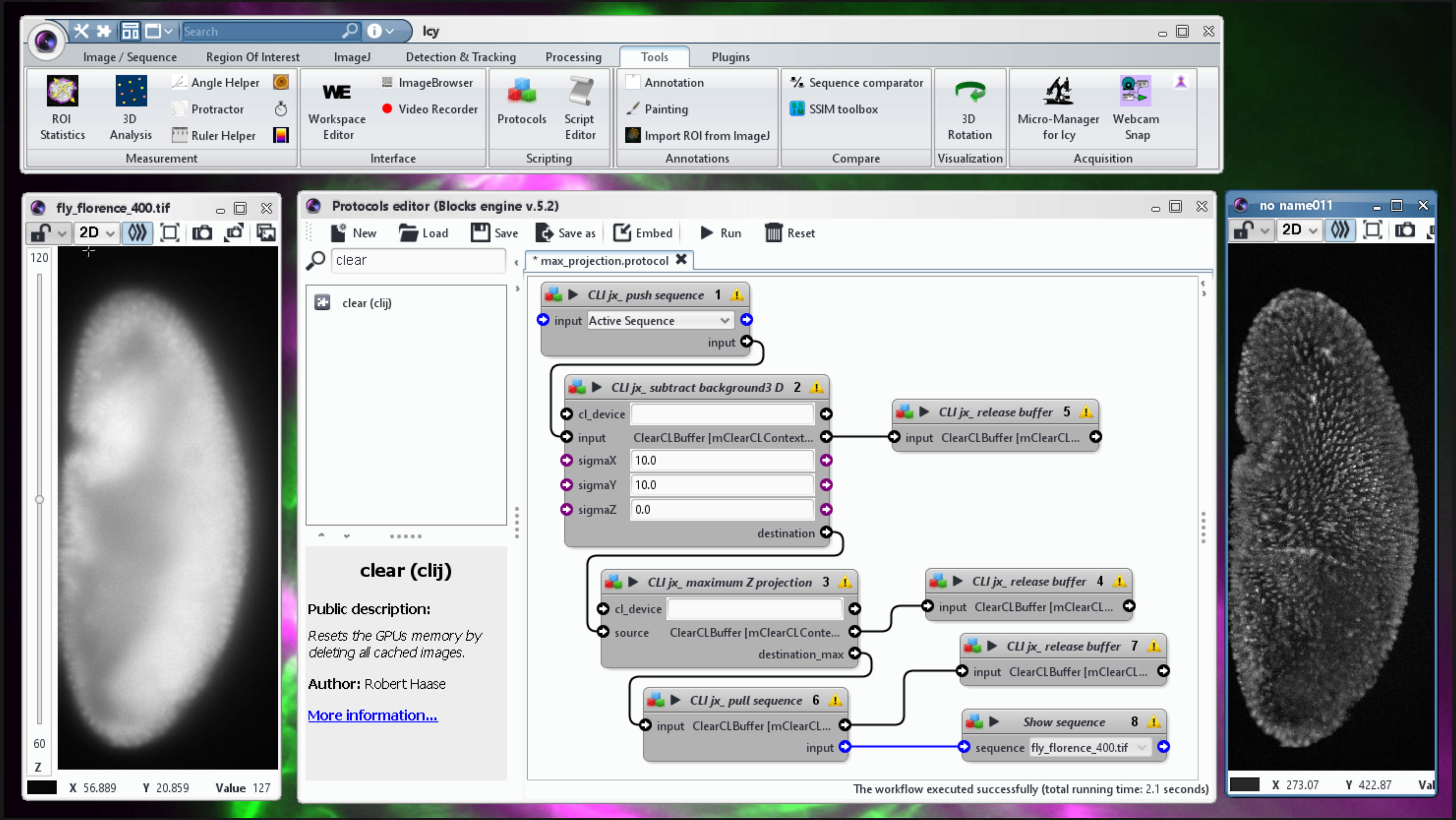
GPU-accelerated image processing for everyone

- Discover operations with Fijis search bar



GPU-accelerated image processing for everyone

- Icy Bioimaging



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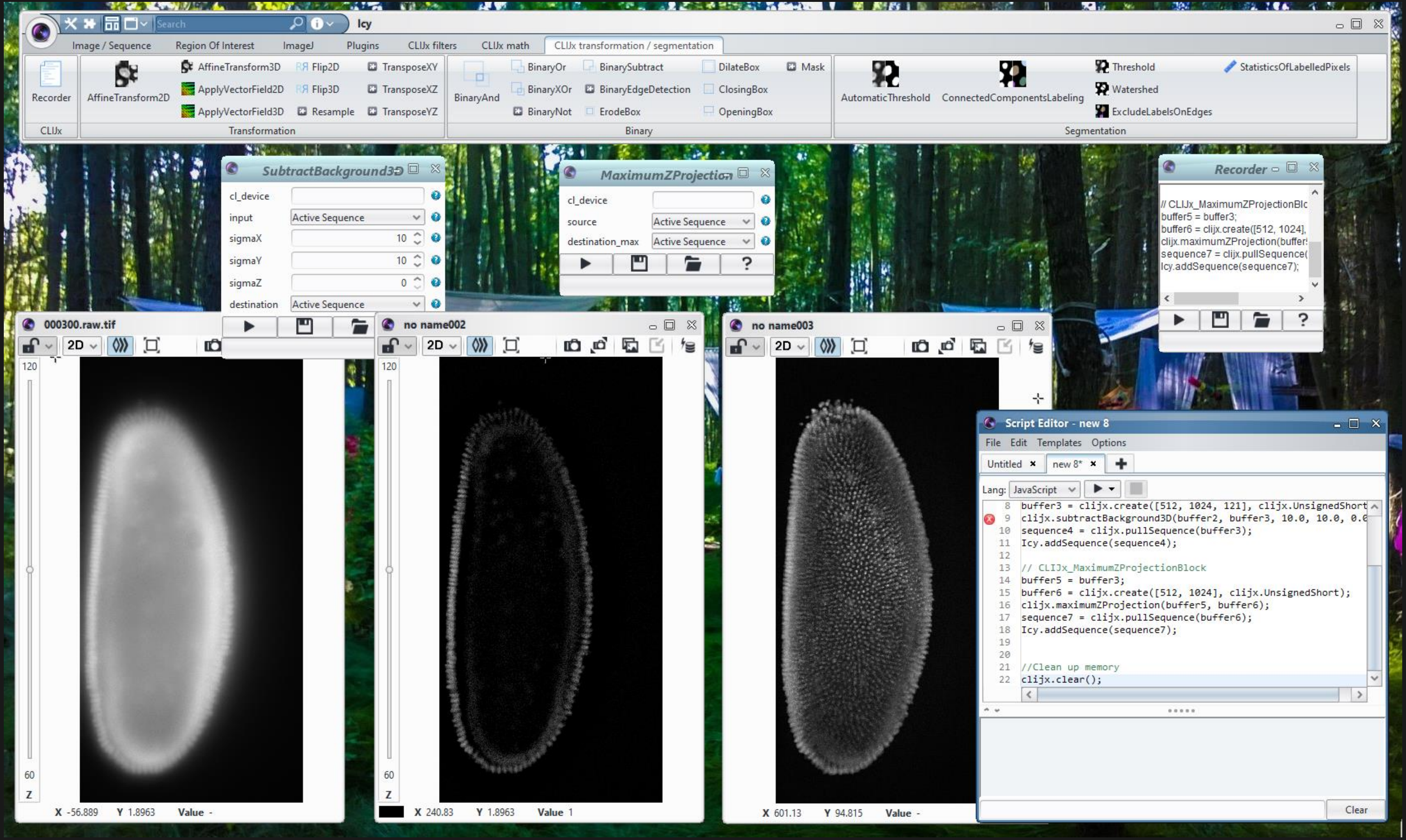
GPU-accelerated image processing for everyone

- Icy got a JavaScript recorder!



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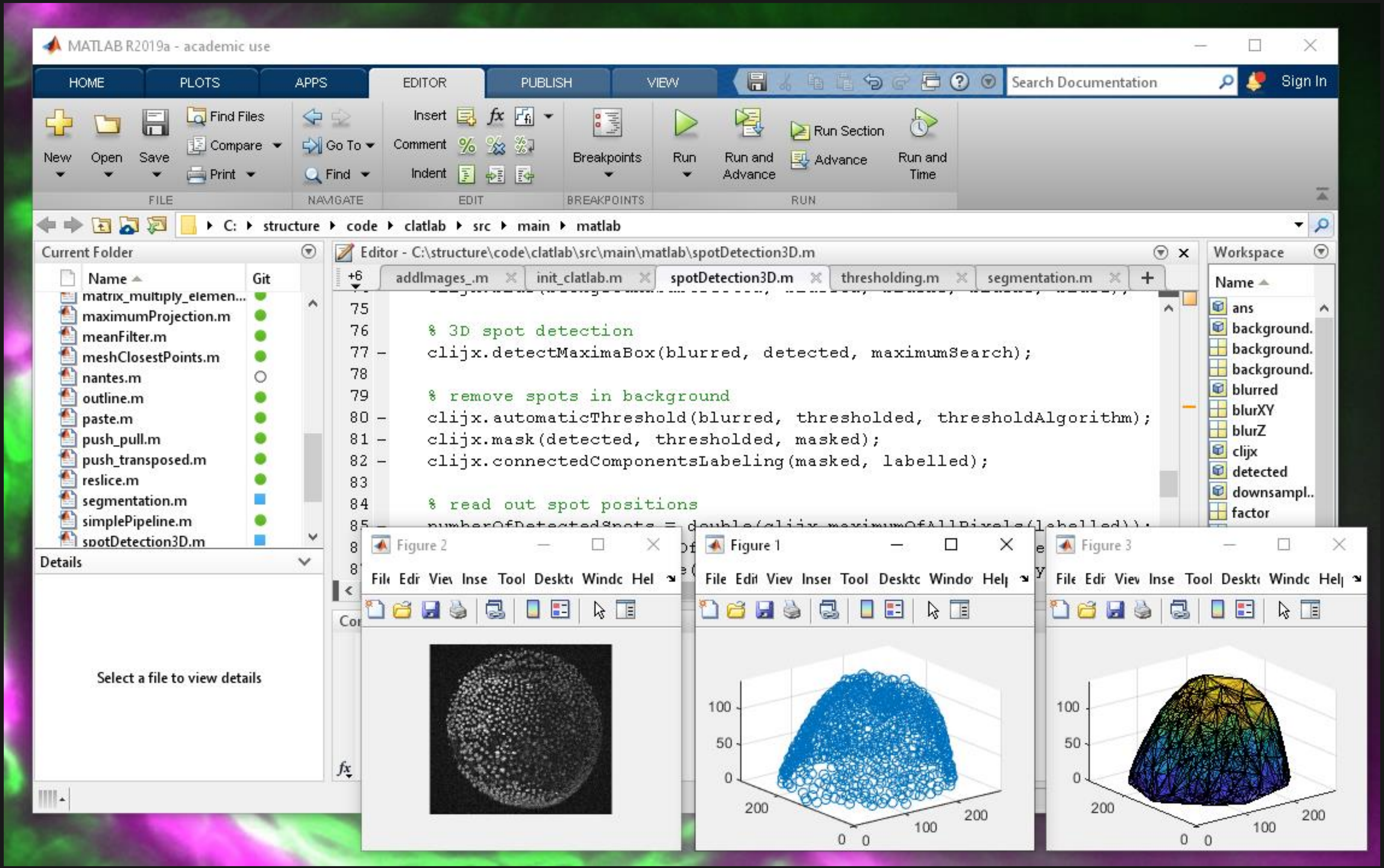
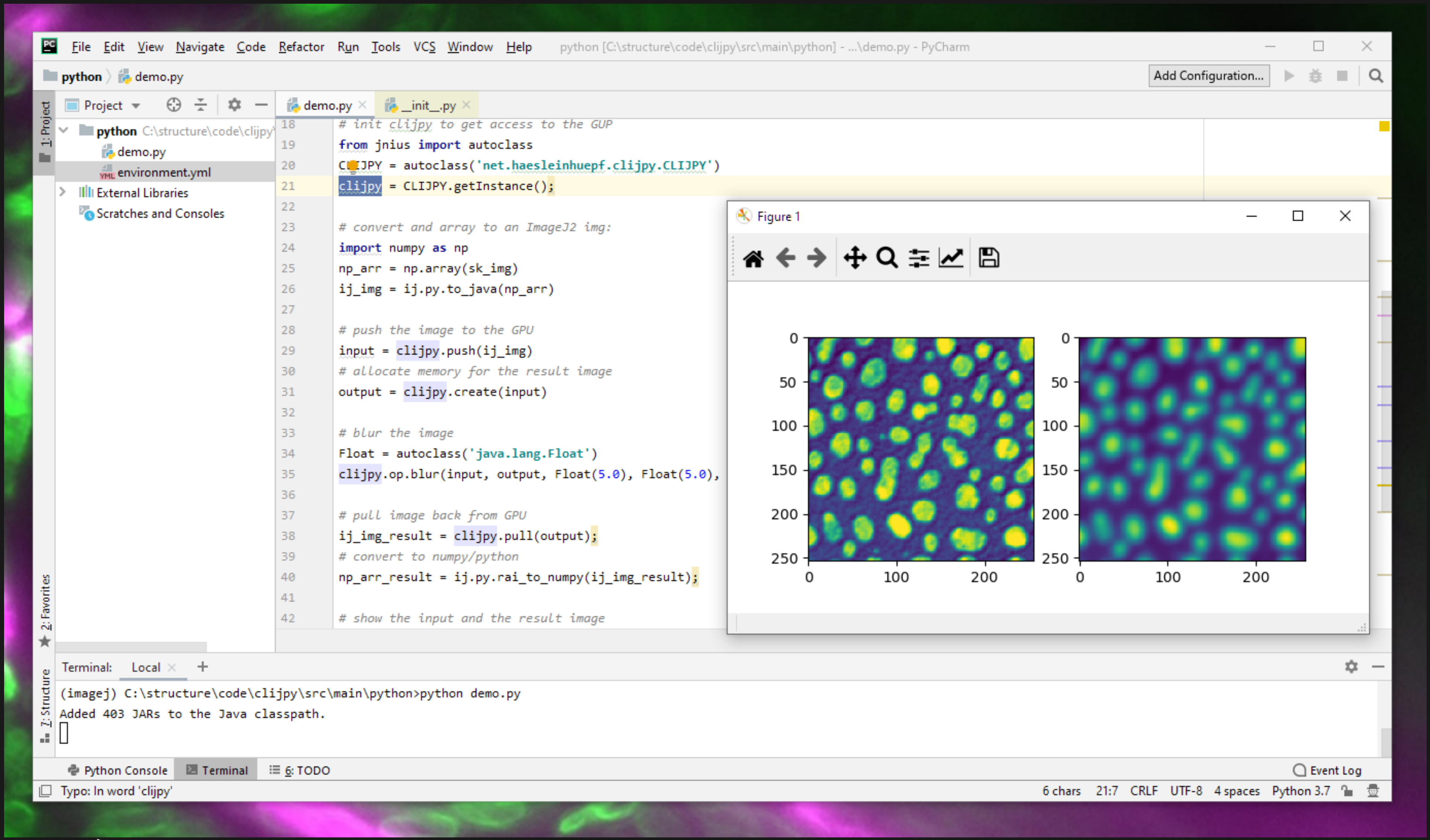
GPU-accelerated image processing for everyone

- Try it in Matlab!



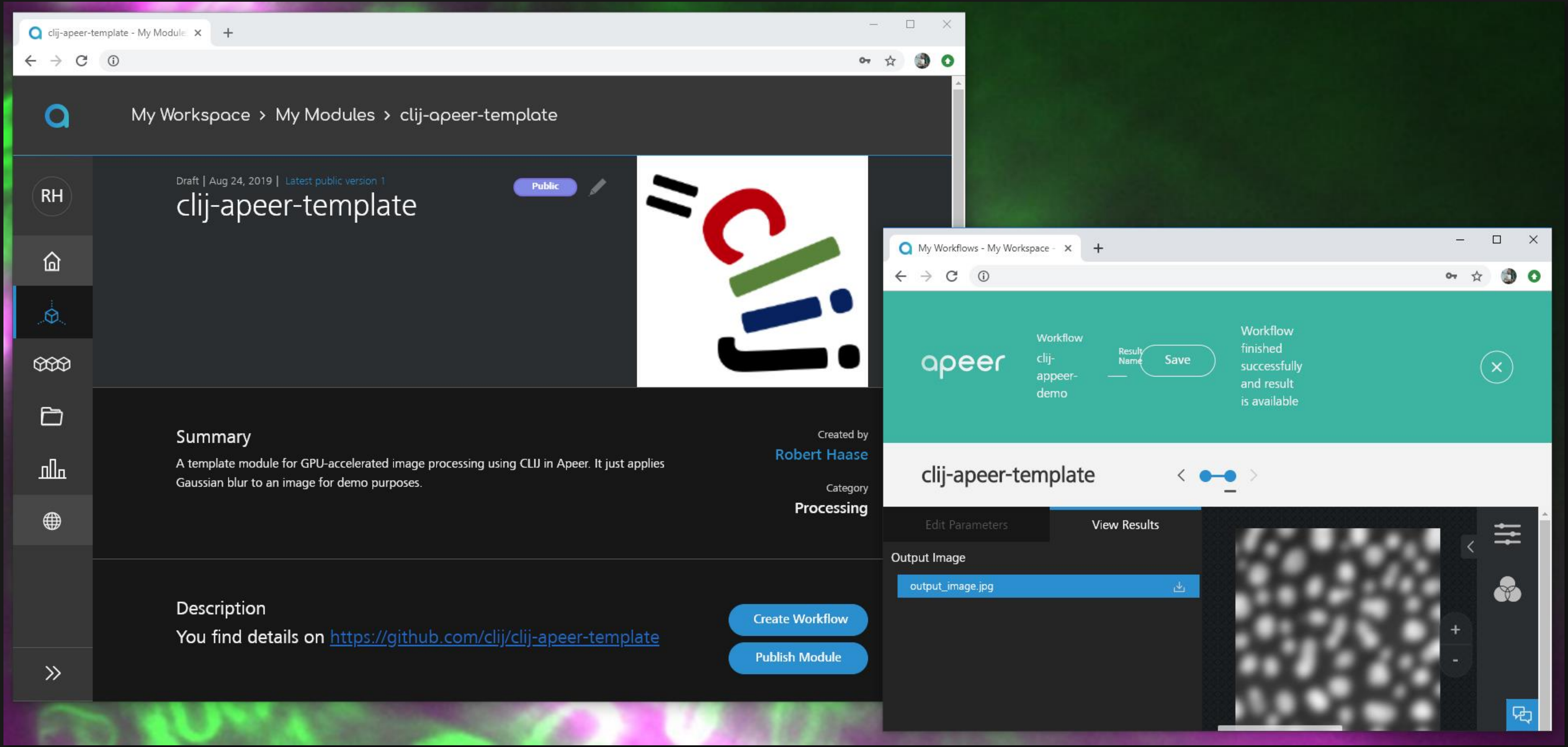
GPU-accelerated image processing for everyone

- Python via PyImageJ



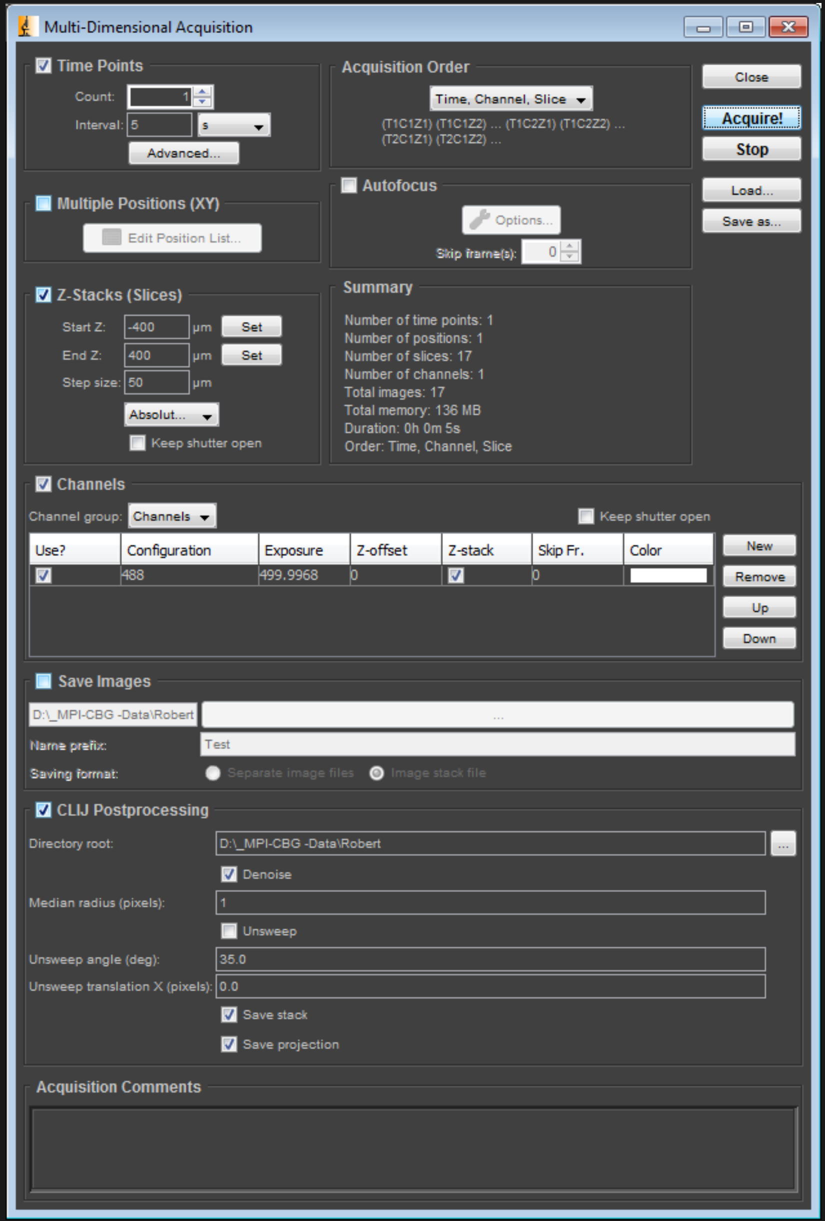
GPU-accelerated image processing for everyone

- Available in the Zeiss Apeer cloud service: https://github.com/clij/clij-apeer-template



GPU-accelerated image processing for everyone

- Work in progress:
  MicroManager integration



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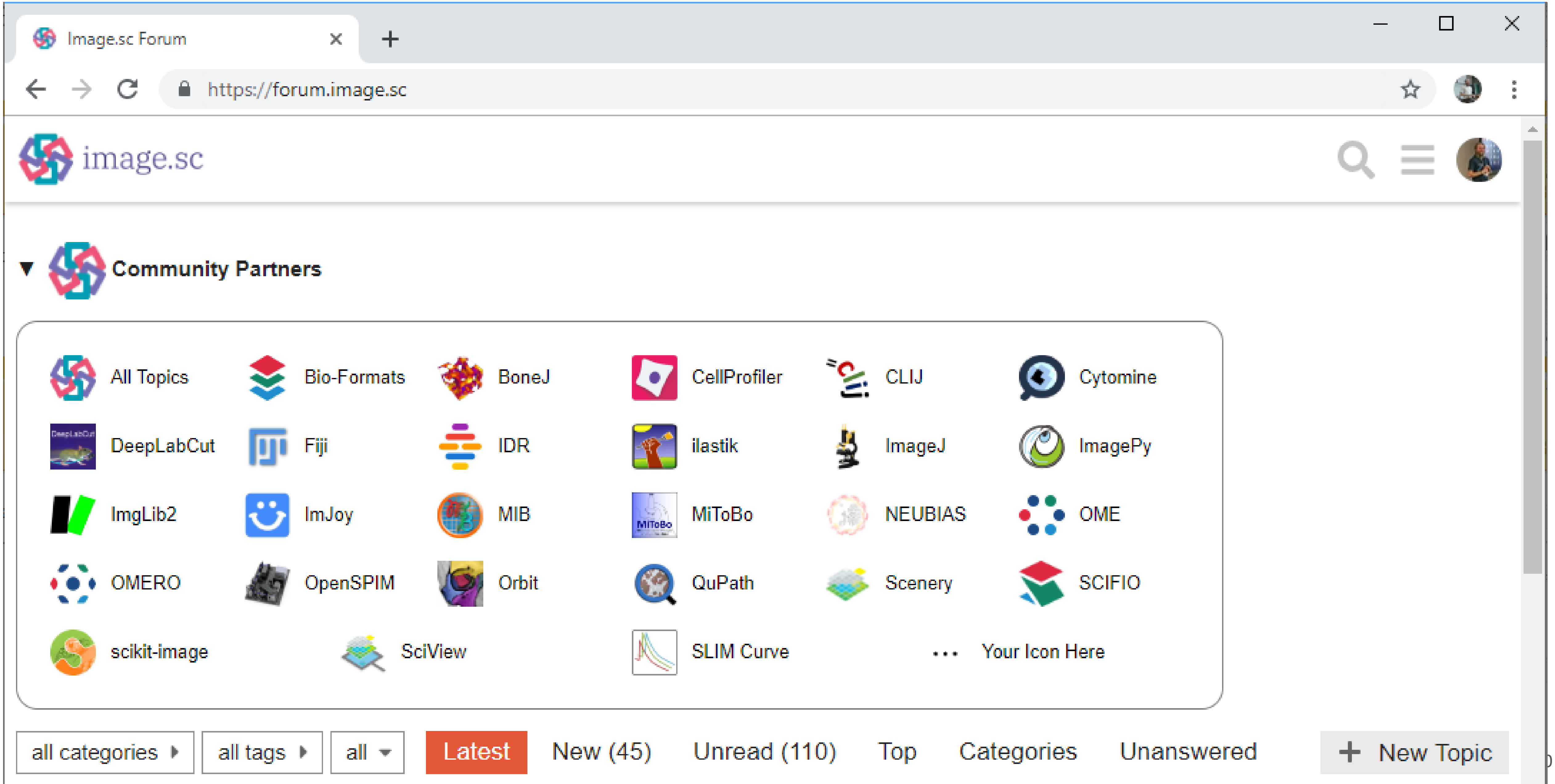
Support: Image.sc



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@a_dibrov


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@uschmidt83


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@martweig


David Chen
(Myers lab)
@bigimaginglab


Debayan Saha
(Myers lab)
@debayan102


Gene Myers
@TheGeneMyers


Nicola Maghelli
(Advanced Imaging Facilitiy)
@aif_cbg


Loic A. Royer
(now at CZ Biohub)
@loicaroyer


Johannes Girstmair
(Tomancak lab)
@jogirstmair


Akanksha Jain
(now Treutlein lab)
@jain_akanksha_


Pavel Tomancak
@PavelTomancak


Deborah Schmidt
(Jug lab)
@frauzufall


Florian Jug
@florianjug

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- Light Microscopy Facility
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- IT Department
- Fly Facility

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