Summary of the ISBI 2013 Grand Challenge on 3D Deconvolution Microscopy

Cédric Vonesch & Stamatios Lefkimmiatis

Biomedical Imaging Group
EPFL, Lausanne, Switzerland

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Thanks to our sponsors!

- ISBI 2013 Grand Challenge Organizers:
  - Stephen Aylward
  - Bram van Ginneken
- Bio Imaging & Signal Processing Technical Committee
- IEEE Signal Processing Society
  - ➡ **Financial support for awards!**
- Funding:

About the organizers

- Main organizers:

Cédric Vonesch
EPFL
Lausanne, Switzerland

Stamatios Lefkimmiatis
EPFL
Lausanne, Switzerland

- Expert committee members:

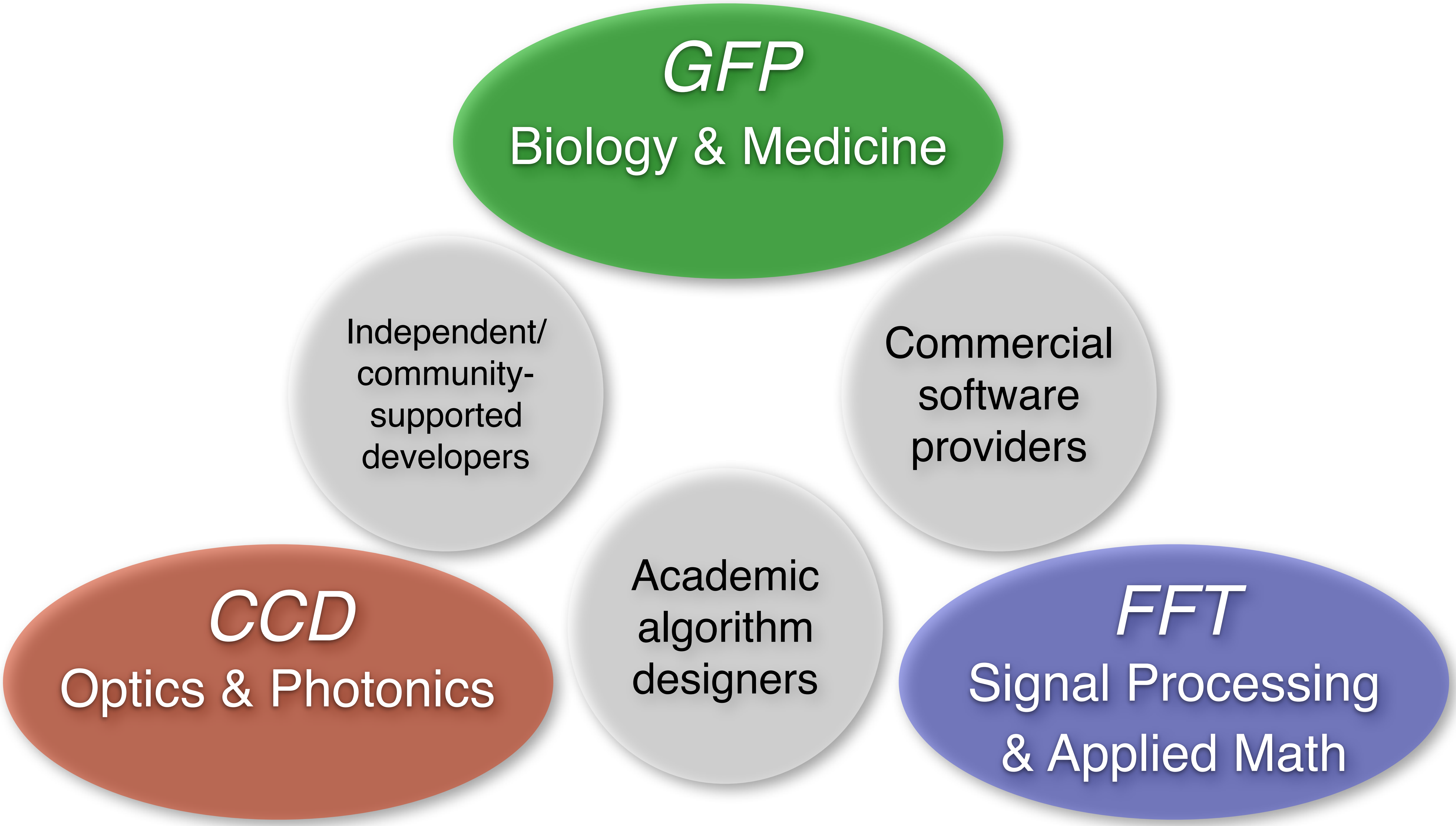
Laure Blanc-Féraud
CNRS
Sophia Antipolis, France

Rainer Heintzmann
Friedrich-Schiller-Universität
Jena, Germany

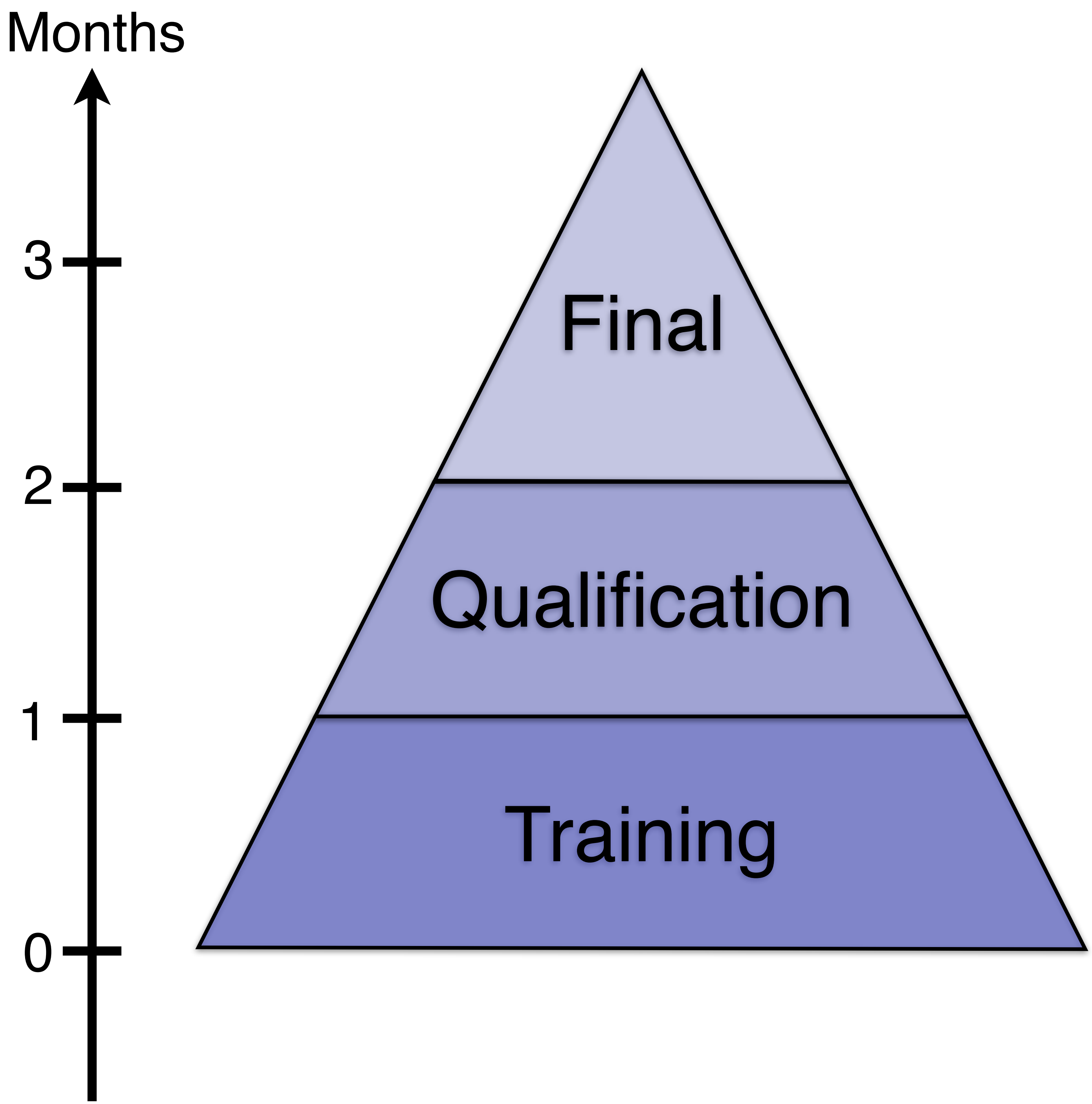
Arne Seitz
EPFL
Lausanne, Switzerland

Michael Unser
EPFL
Lausanne, Switzerland

Primary goal: promoting cross-fertilization



Overview of the challenge



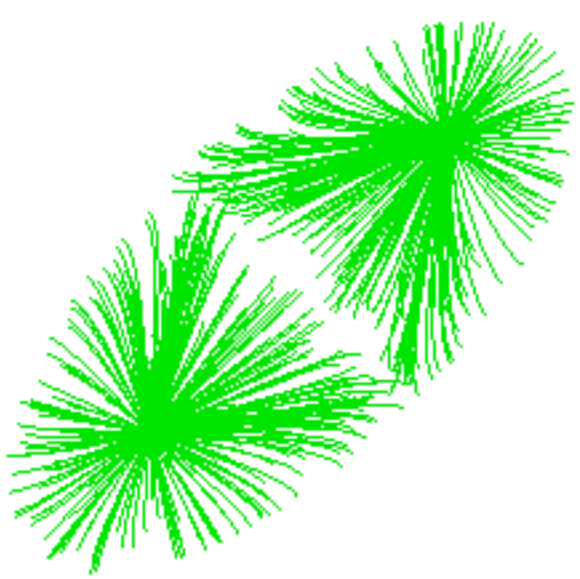
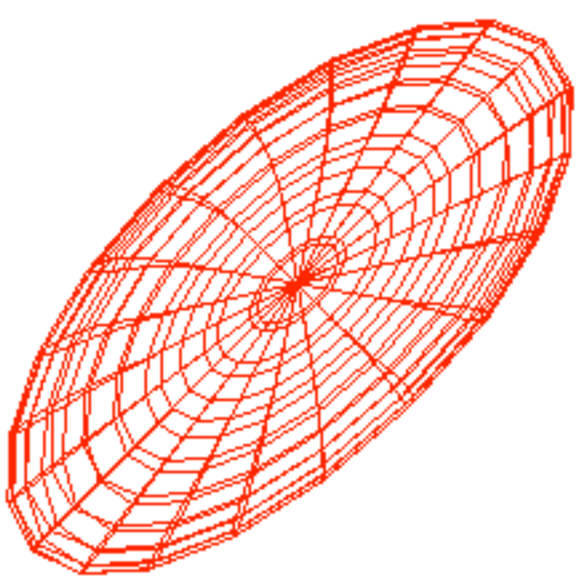
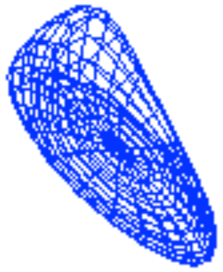
- ISBI special session
- Invite participants with best results to present their method

- Determine the performance of proposed methods
- Larger data, less oracle information

- Familiarize participants with data sets, forward model, metrics...
- Simplified setting

Typology of the phantom data

Manifold dimension	Structural class	Mathematical representation	Corresponding biological objects	Stain example	Color channel	λ (nm)
0	Point sources, sub-resolution structures	Dirac distributions, narrow B-splines	Single molecules, vesicles, mitochondria	MitoTracker	Yellow/ Orange	600
1	Curves	Bézier polynomials	Microtubules, actin filaments	GFP	Green	525
2	Surfaces	Deformable ellipsoidal contours	Cellular or nuclear membranes	DiD	Deep Red	675
3	Dense volumes	Wide B-splines	Condensing chromatine, DNA	DAPI, Hoechst	Blue	450

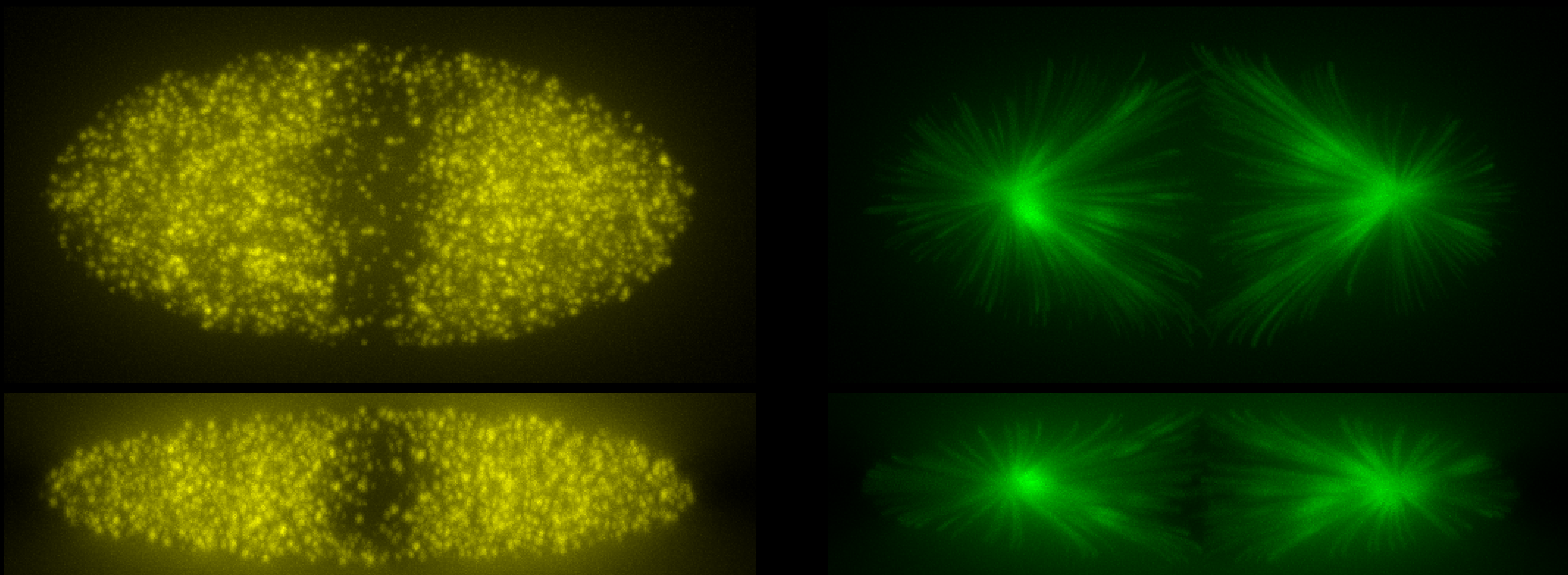
Summary of the forward model

$$\mathbf{y} = Q\Big(\mathcal{P}(\mathbf{T}\mathbf{x} + \mathbf{b}) + \mathcal{N}(\mathbf{0}, \sigma^2\mathbf{I})\Big)$$

Notations:

- $\mathbf{x}$: ground-truth fluorophore distribution
- $\mathbf{T}$: block-Toeplitz matrix
- $\mathbf{b}$: background signal (constant vector)
- σ^2: variance of Gaussian noise
- Q: quantization and clipping operator $$Q(x) = \begin{cases} \arg\min_{n\in\mathbb{N}} |x - n| & \text{if } x > 0, \\ 0 & \text{otherwise} \end{cases}$$

Simulated micrographs (Maximum-intensity projections)



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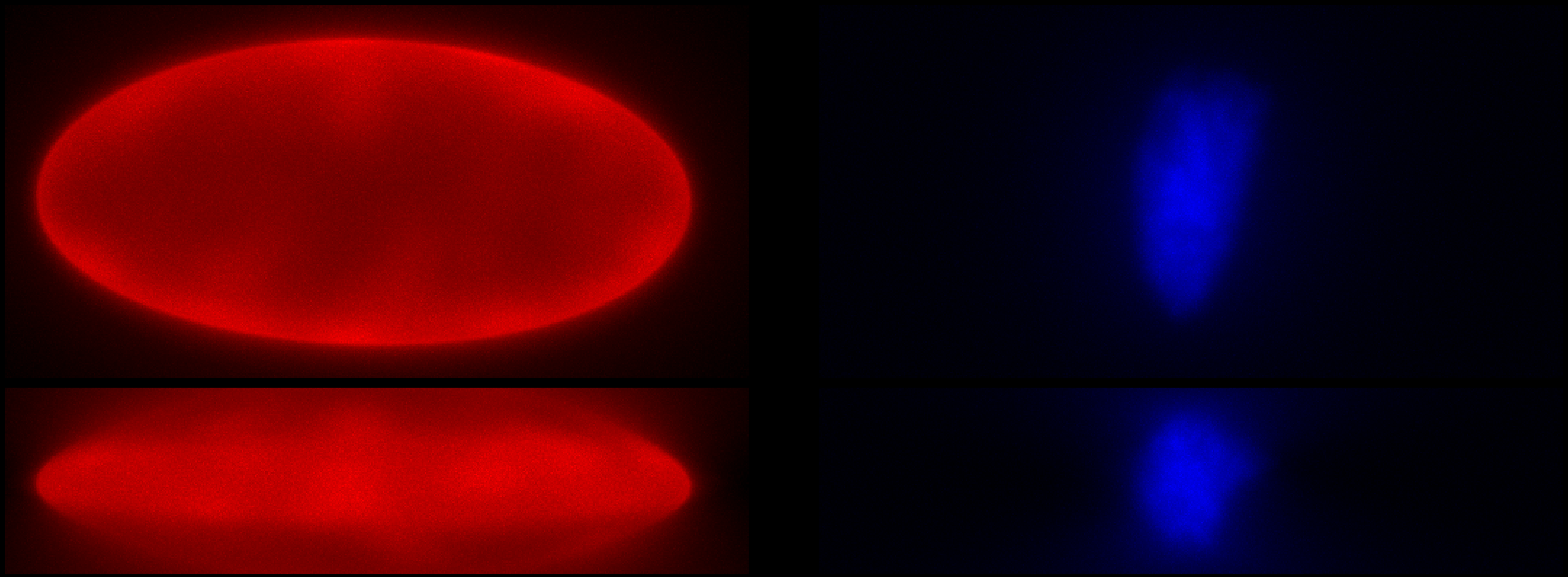


Performance Metrics

- MSE-based Metrics
  - Increase in signal-to-noise ratio (ISNR)

$$\mathrm{ISNR} = 20\log_{10}\frac{\|\mathbf{y}-\mathbf{x}\|_2}{\|\hat{\mathbf{x}}-\mathbf{x}\|_2}$$

$\mathbf{x}$: ground-truth

$\hat{\mathbf{x}}$: affine regressed reconstruction

  - Normalized mean integrated squared error (NMISE)

$$\mathrm{NMISE} = \frac{1}{N}\sum_{n=1}^{N}\frac{\left[\mathbf{T}\left(\mathbf{x}-\hat{\mathbf{x}}\right)\right]_n^2}{\left[\mathbf{T}\mathbf{x}\right]_n}$$

- Structure Similarity Index (SSIM)
  - Better correlation with human eye perception than SNR
  - Mean-SSIM, Minimum-SSIM (over all slices of the 3D volume)
- Wavelet sparsity index
  - Measure of the number of nonzero coefficients in the wavelet domain

Performance Metrics

- Derivative-based metrics
  - Relative total variation error

$$R = \frac{\sum_{n=1}^{N} \left\| [\nabla \hat{\mathbf{x}}]_n - [\nabla \mathbf{x}]_n \right\|_2}{\sum_{n=1}^{N} \left\| [\nabla \mathbf{x}]_n \right\|_2}$$

  - Relative structure-tensor error

$$R = \frac{\sum_{n=1}^{N} \left| \left\| [\mathbf{S}\hat{\mathbf{x}}]_n \right\| - \left\| [\mathbf{S}\mathbf{x}]_n \right\| \right|}{\sum_{n=1}^{N} \left\| [\mathbf{S}\mathbf{x}]_n \right\|}$$

$$\mathbf{S}\mathbf{x} = \mathbf{G} * \left(\nabla \mathbf{x} \, \nabla \mathbf{x}^T \right)$$

$$\left\| [\mathbf{S}\mathbf{x}]_n \right\| = \sum_{k=1}^{3} \sqrt{[\lambda_k]_n}$$

  - Relative Hessian-Frobenius error

$$R = \frac{\sum_{n=1}^{N} \left| \left\| [\mathbf{H}\hat{\mathbf{x}}]_n \right\|_{\mathrm{F}} - \left\| [\mathbf{H}\mathbf{x}]_n \right\|_{\mathrm{F}} \right|}{\sum_{n=1}^{N} \left\| [\mathbf{H}\mathbf{x}]_n \right\|_{\mathrm{F}}}$$

$$\left\| [\mathbf{H}\mathbf{x}]_n \right\|_{\mathrm{F}} = \sqrt{[\lambda_1]_n^2 + [\lambda_2]_n^2 + [\lambda_3]_n^2}$$

Performance Metrics

- Fourier-based metrics
  - Fourier shell correlation: measures the normalized cross-correlation coefficient between two 3D volumes over corresponding shells in Fourier space

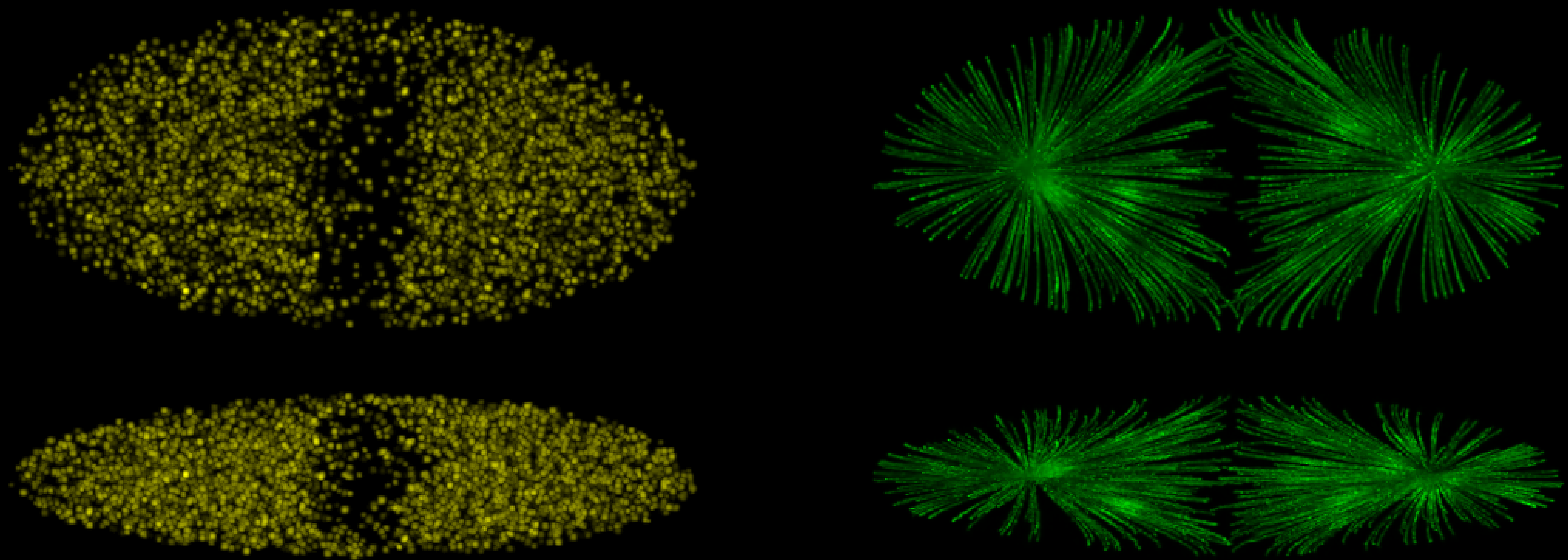
$$\mathrm{FSC}(\omega) = \frac{\sum_{\omega_i \in \omega} \hat{X}(\omega_i) \cdot X^*(\omega_i)}{\sqrt{\sum_{\omega_i \in \omega} |\hat{X}(\omega_i)|^2 \cdot \sum_{\omega_i \in \Omega} |X(\omega_i)|^2}}$$

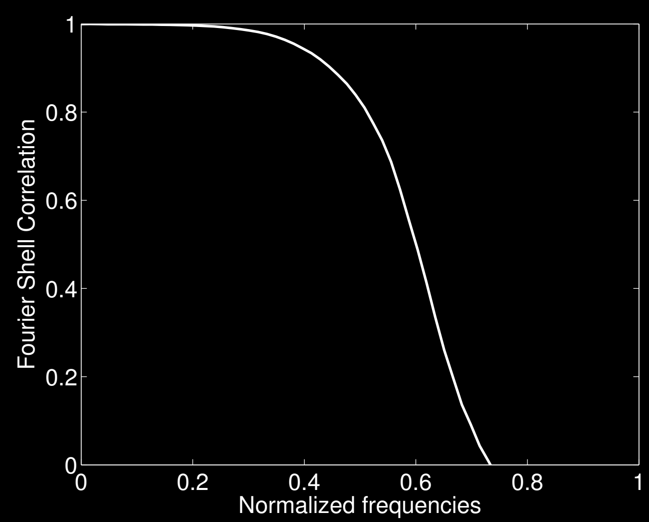
  - Relative energy regain

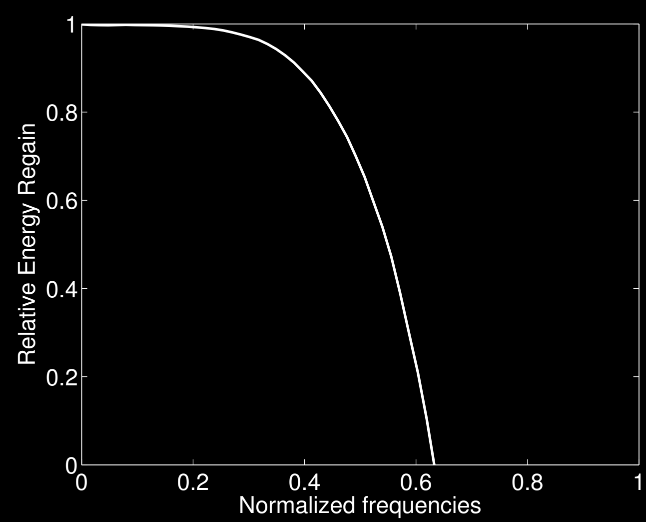
$$G_R(\omega) = 1 - \frac{\sum_{\omega_i \in \omega} |\hat{X}(\omega_i) - X(\omega_i)|^2}{\sum_{\omega_i \in \omega} |X(\omega_i)|^2}$$

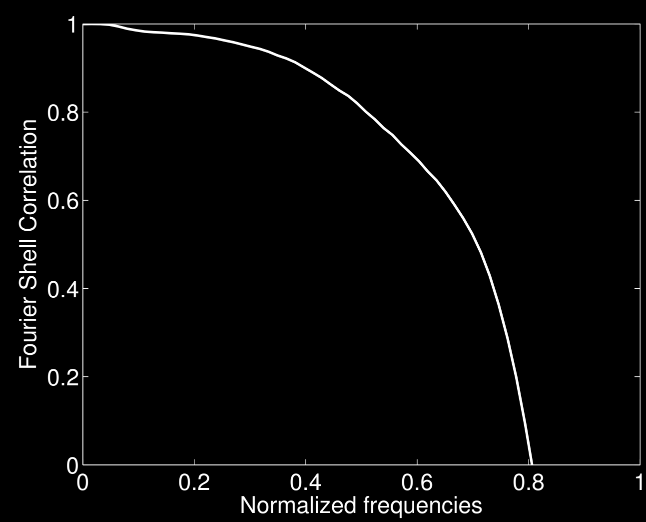
    - $G_R(\omega) = 1$: spatially frequency domain perfectly reconstructed
    - $G_R(\omega) = 0$: no available frequency information

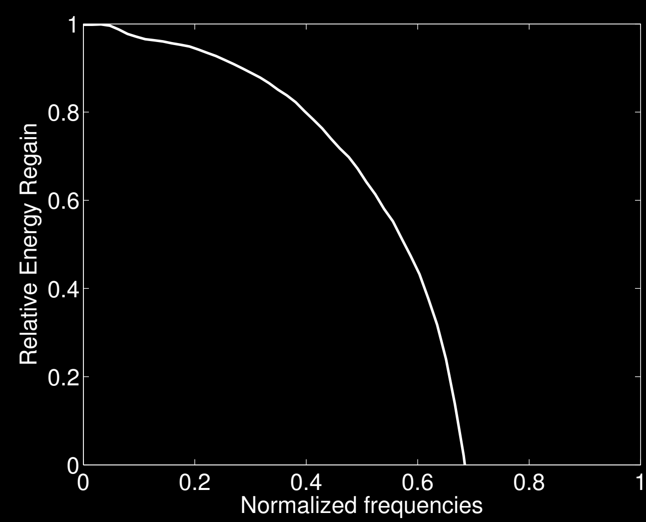
Results (top submissions)











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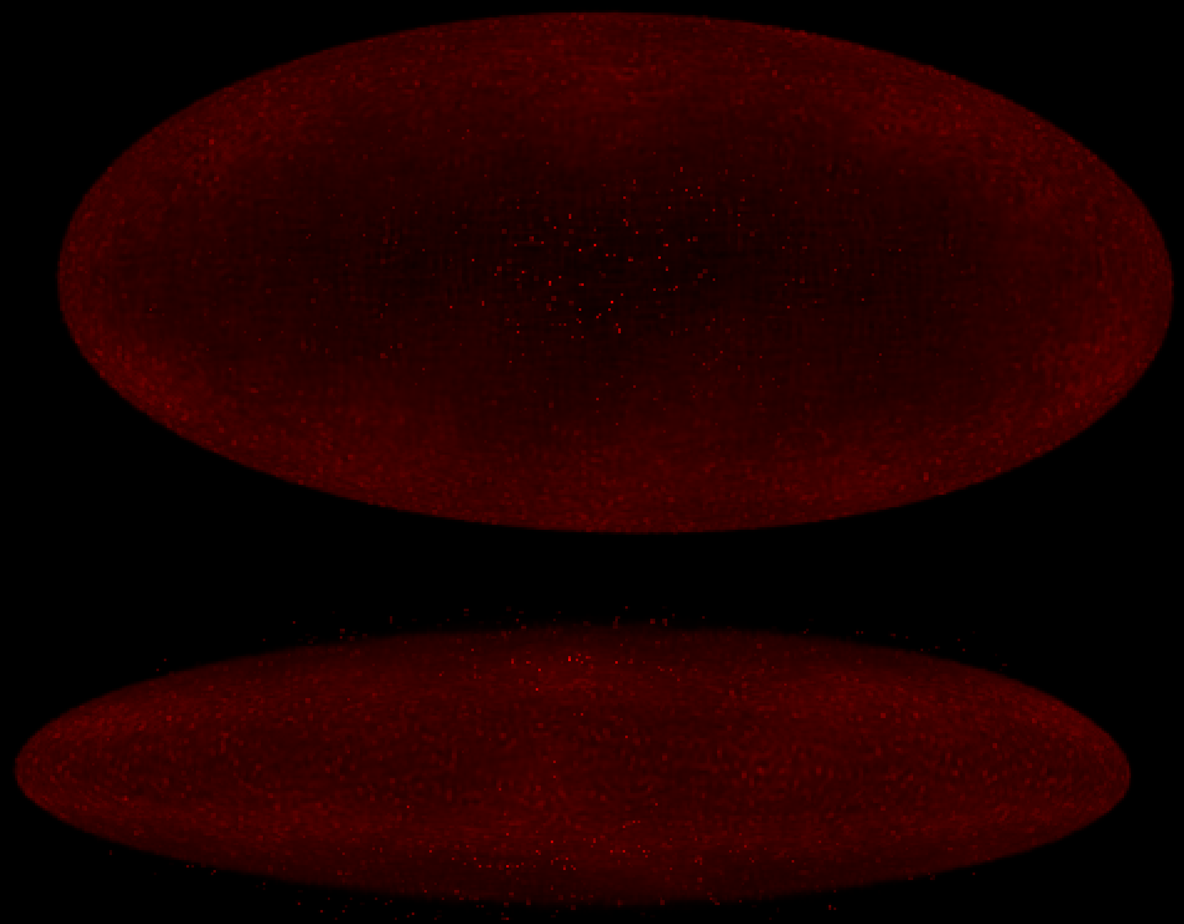

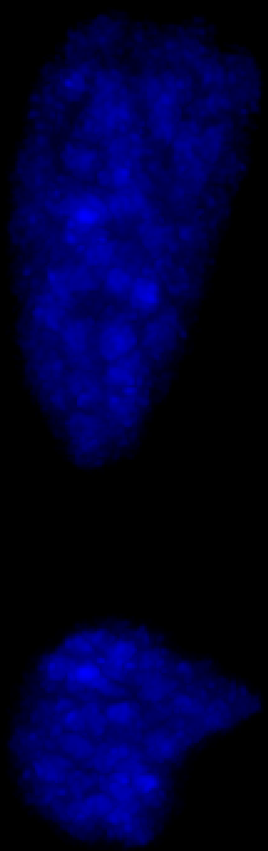

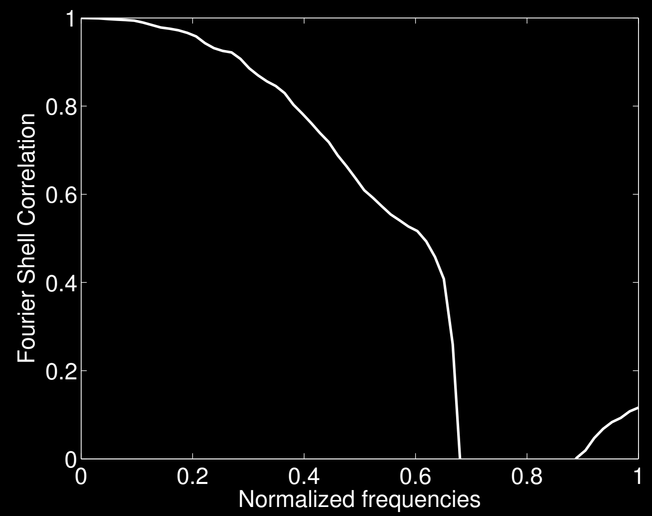

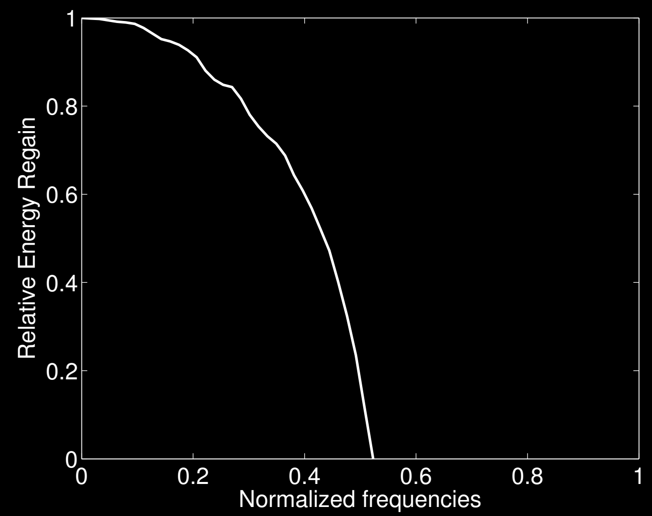

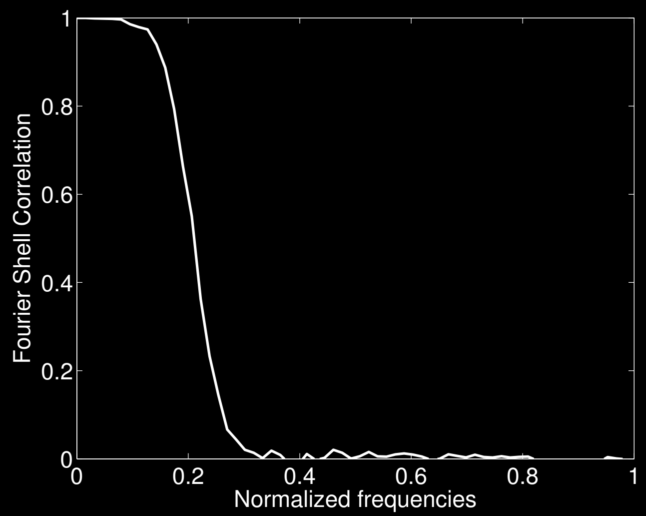

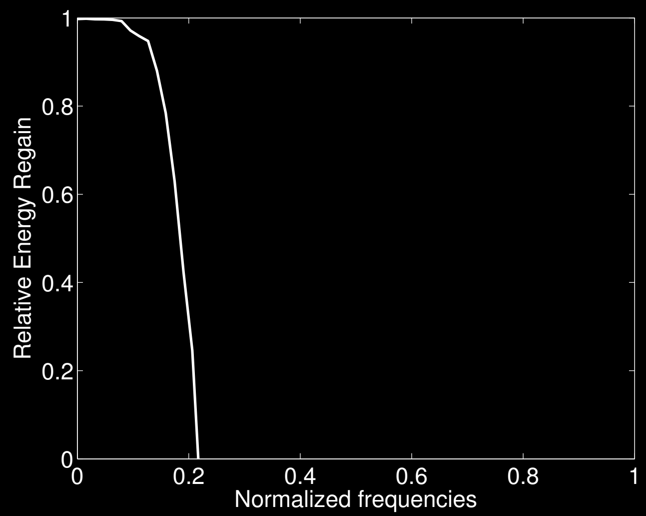

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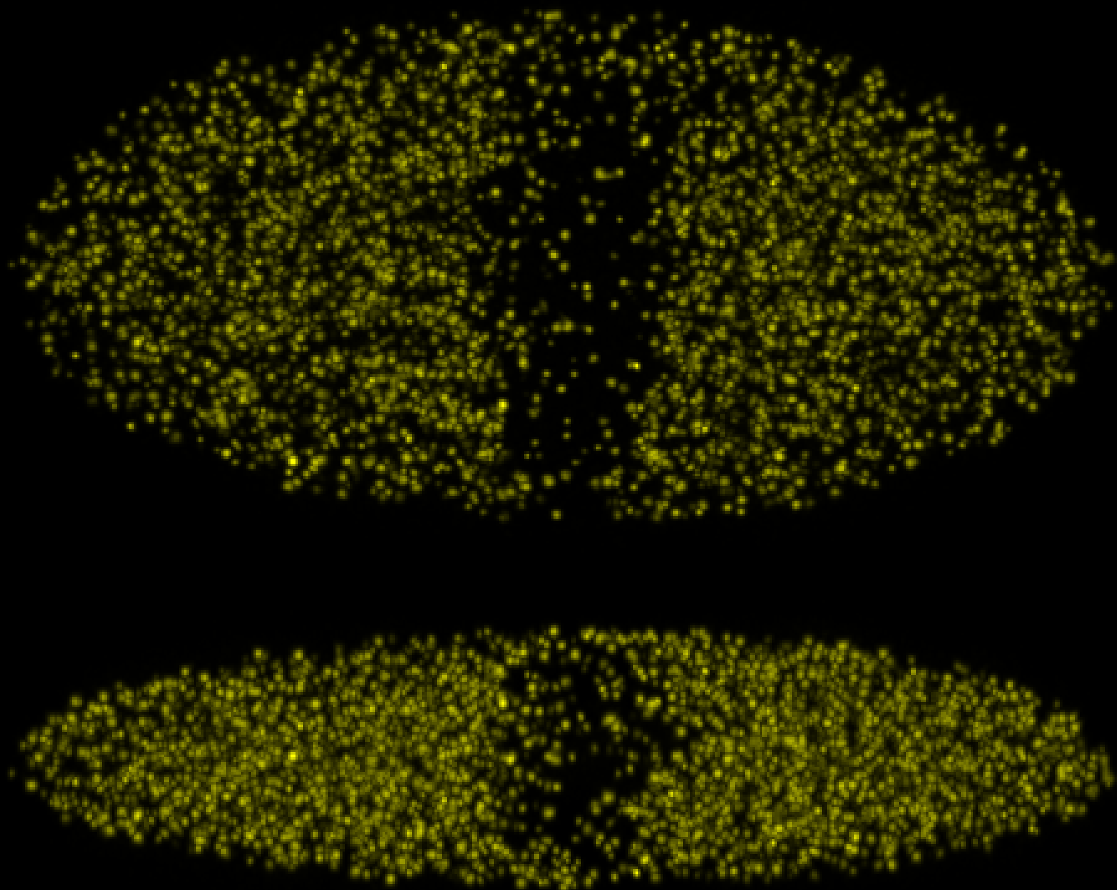

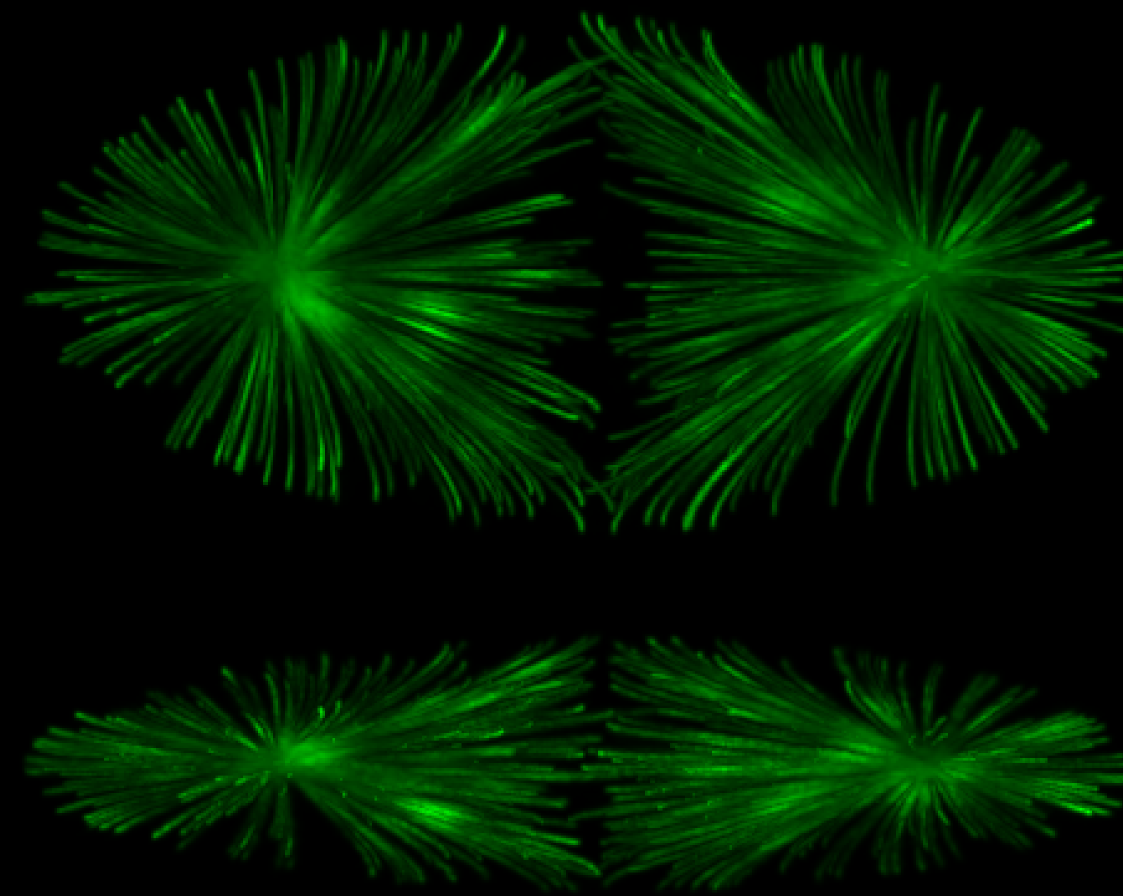

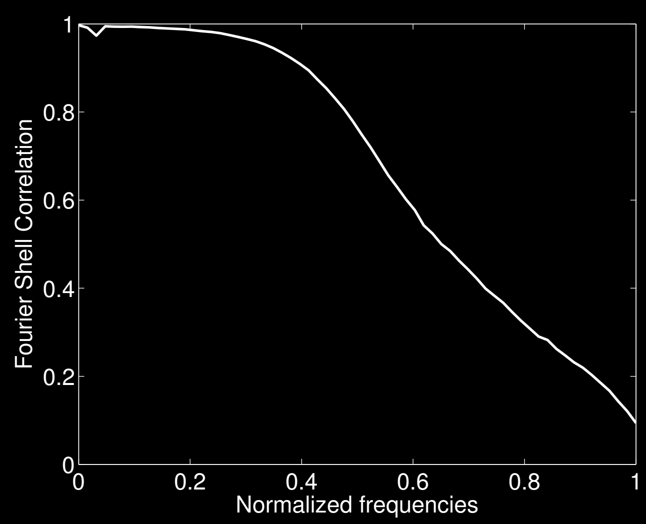

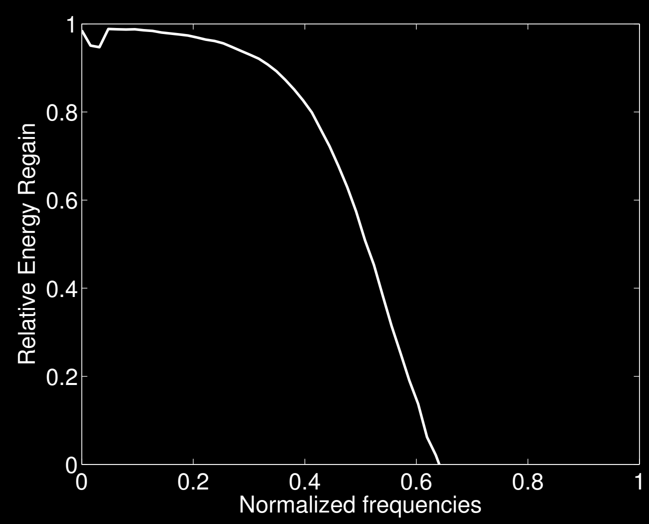

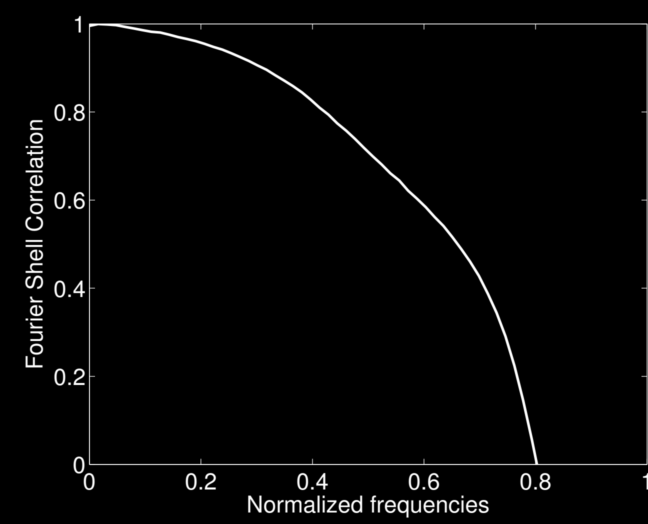

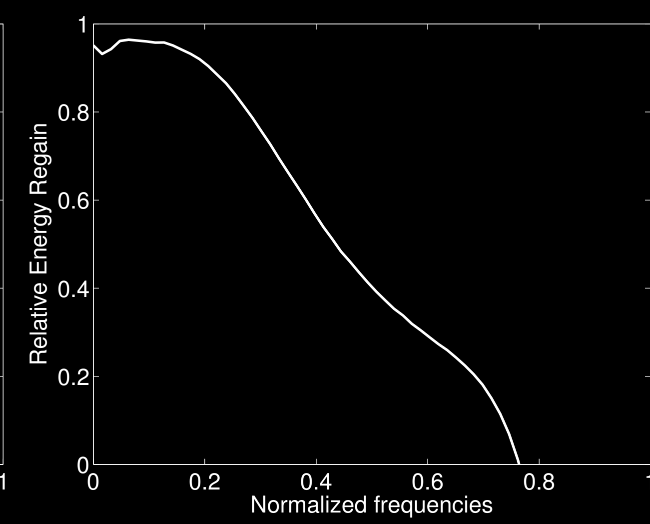

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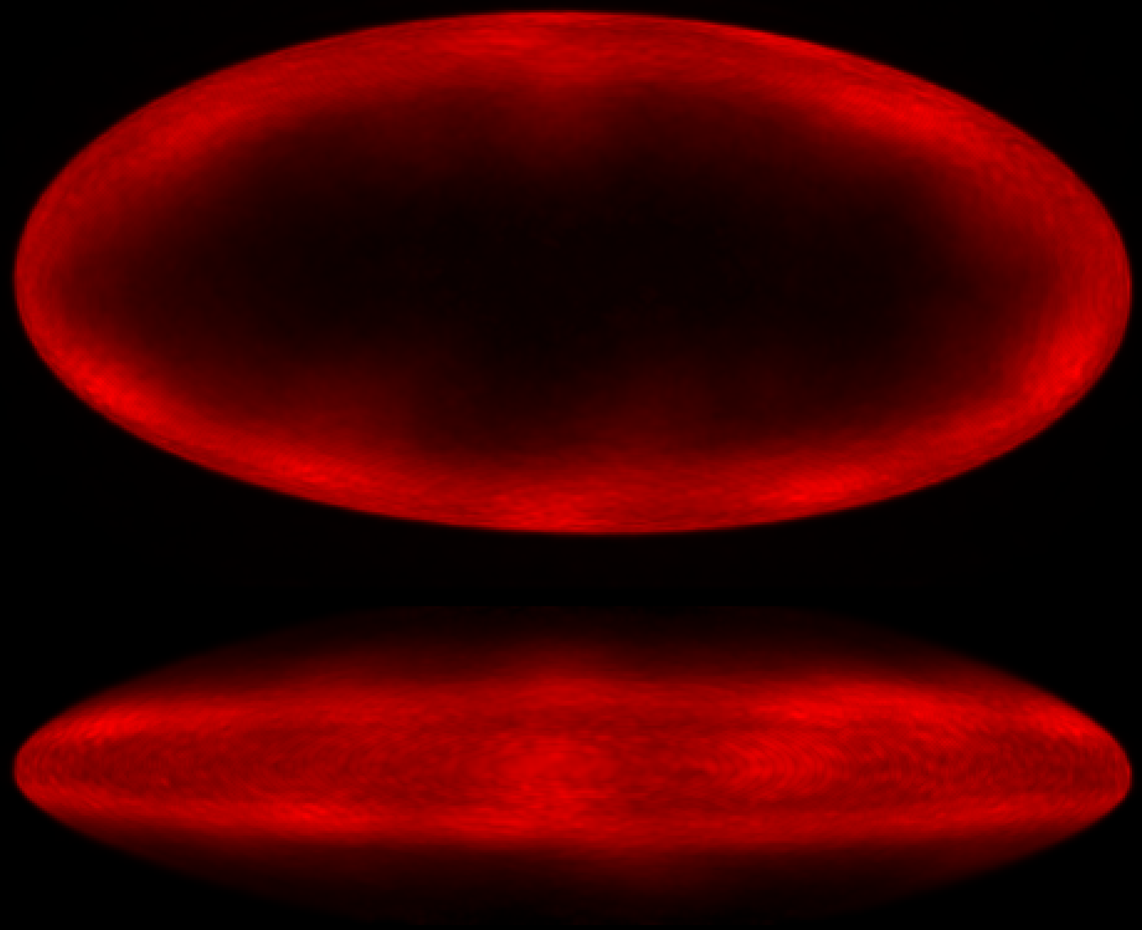

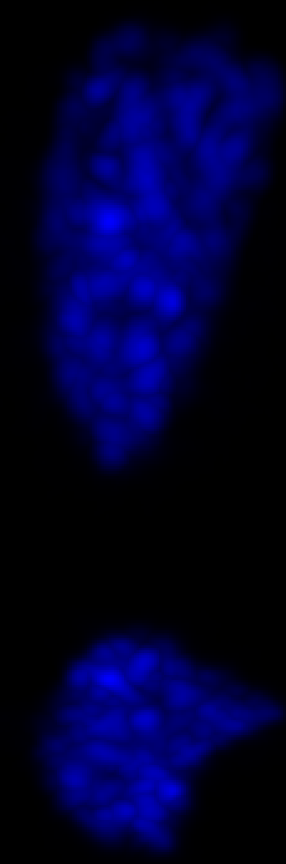

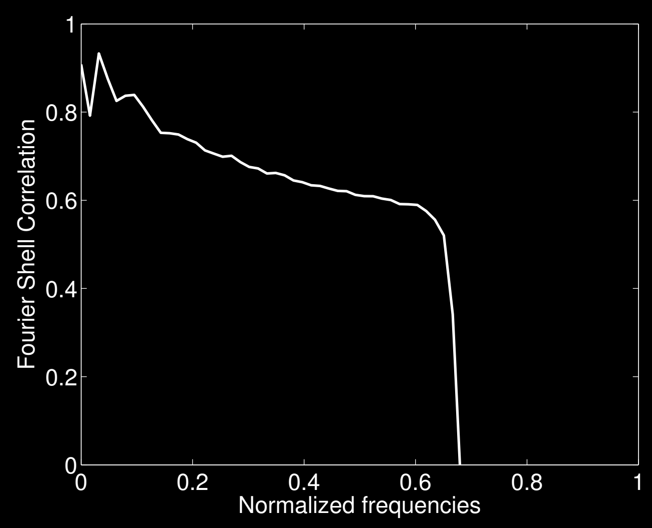

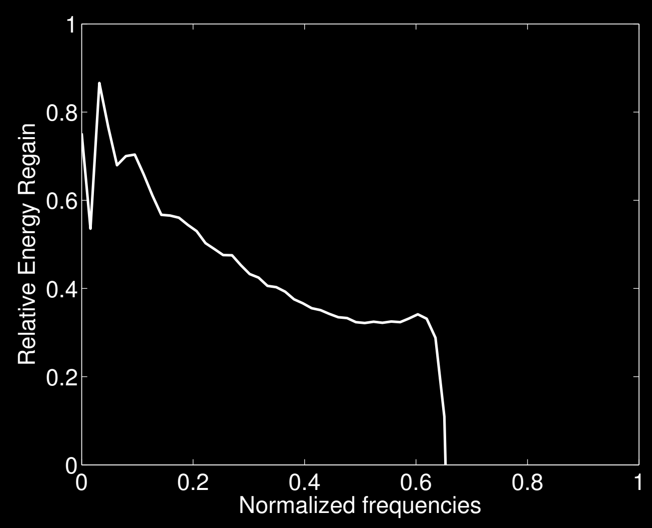

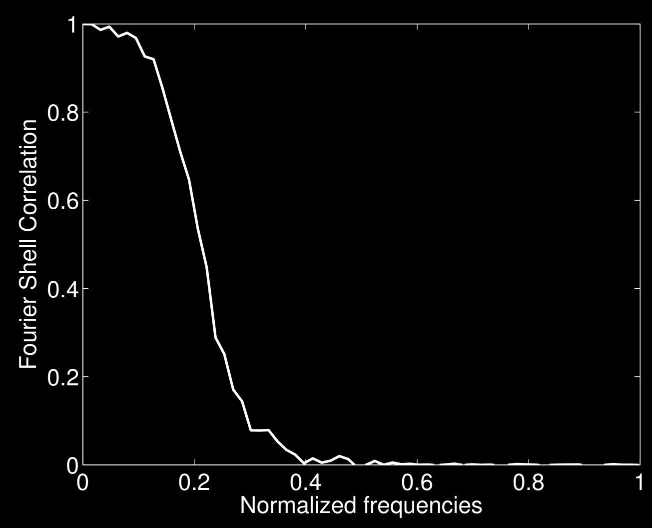

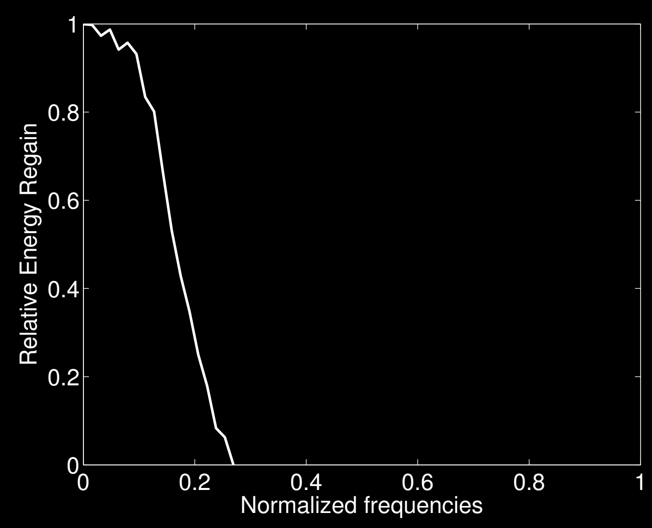

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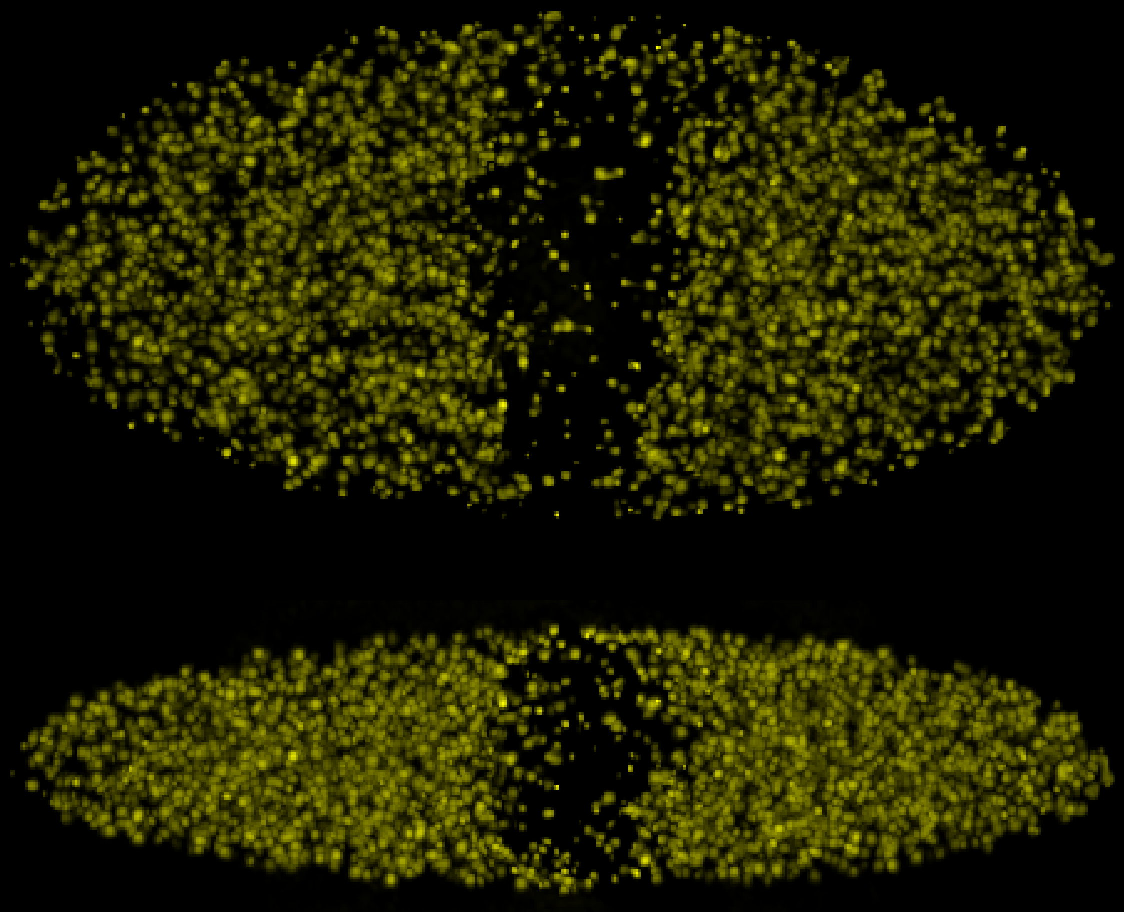

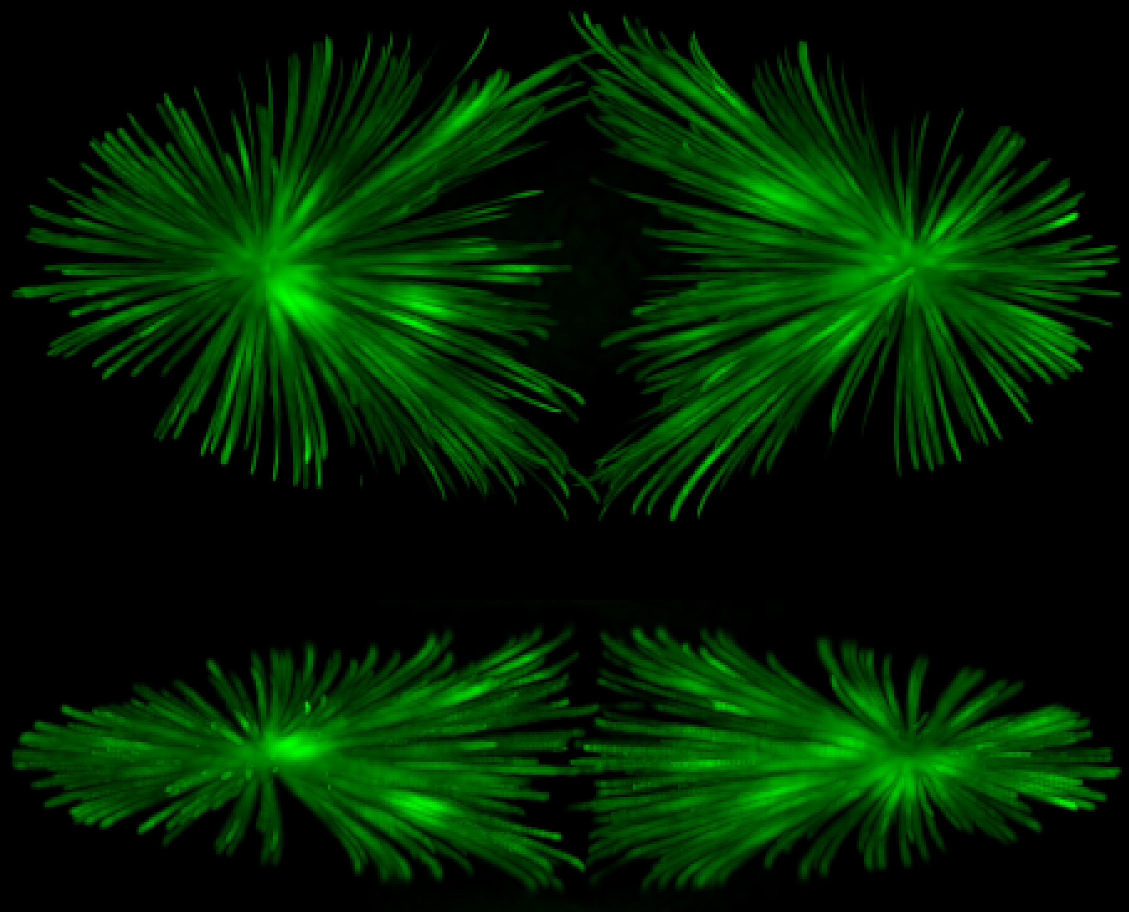

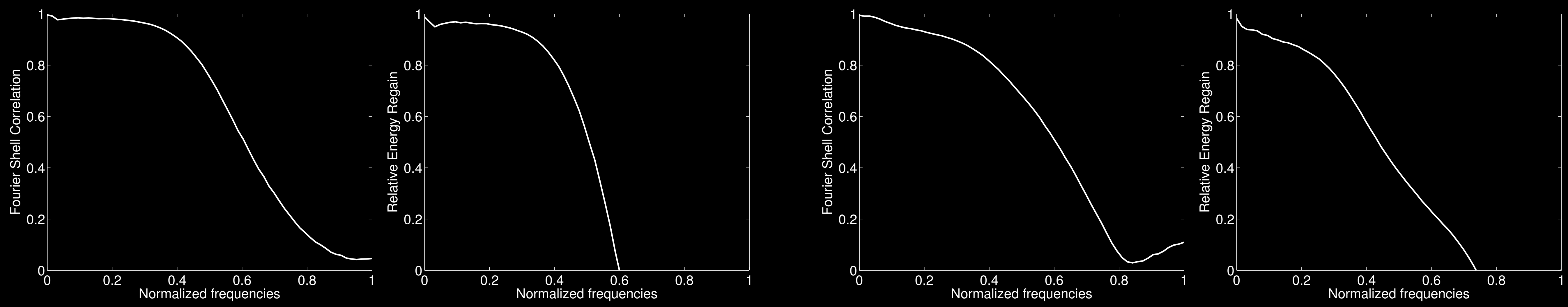

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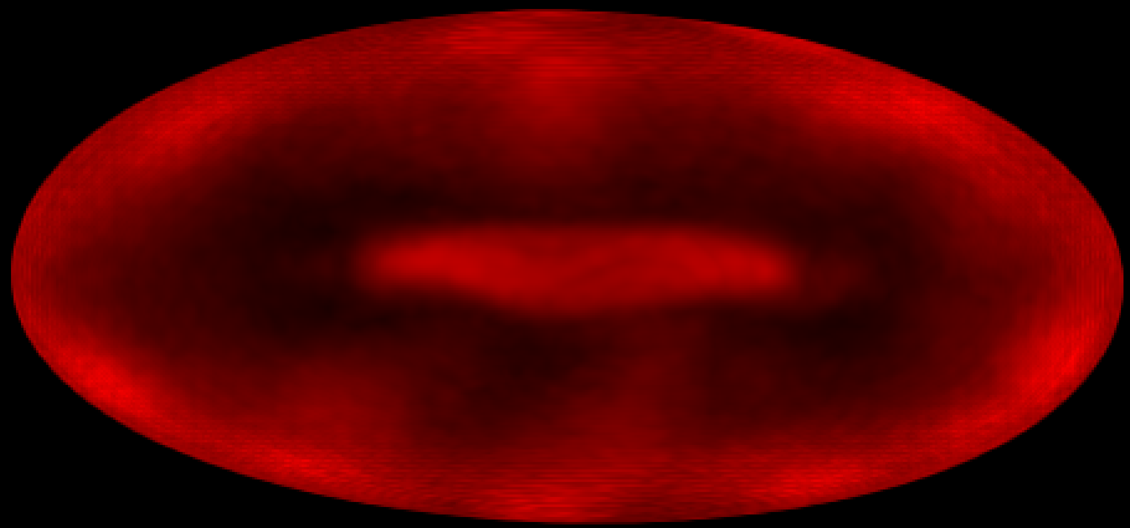
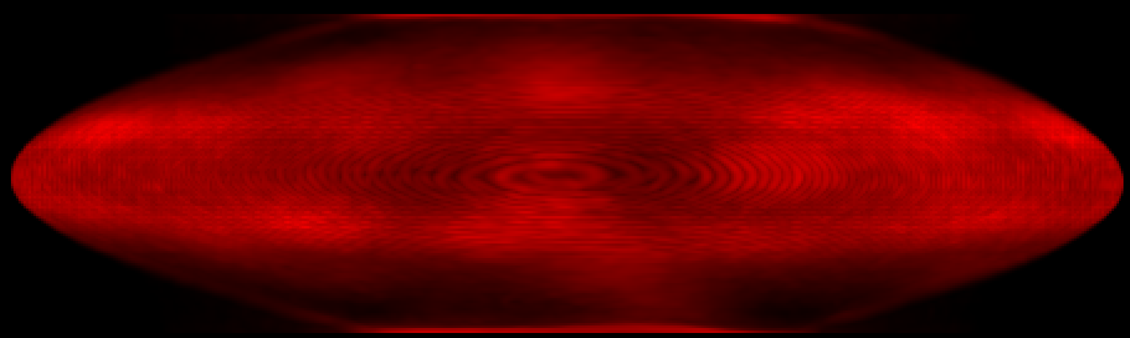
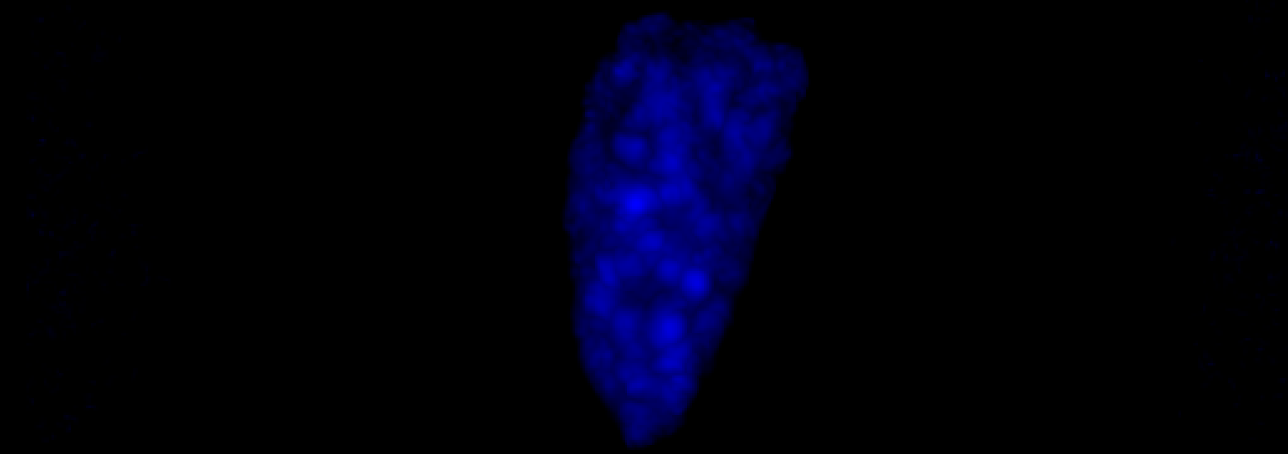
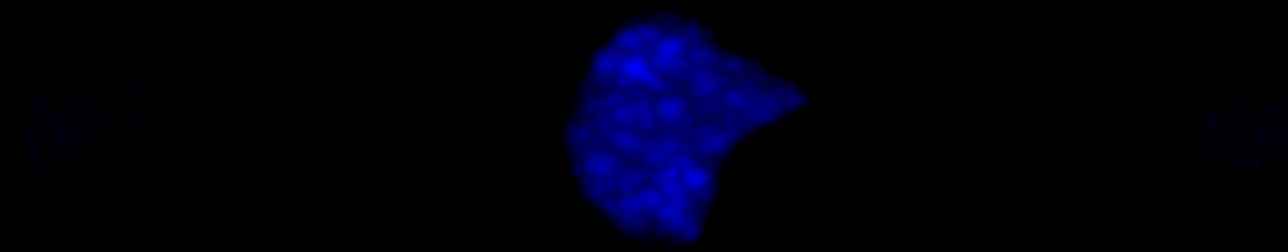
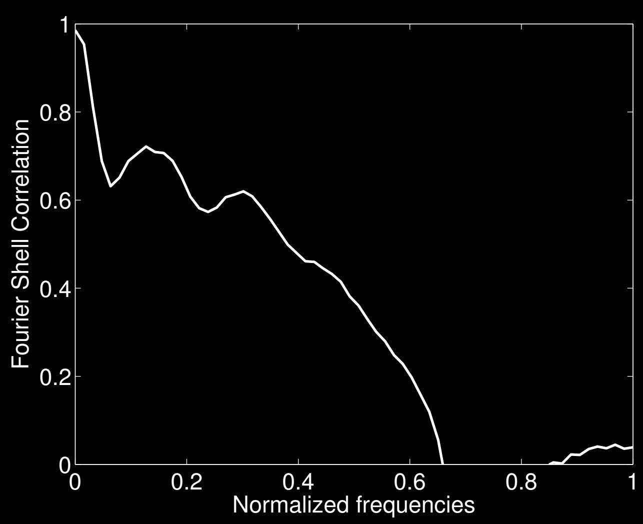
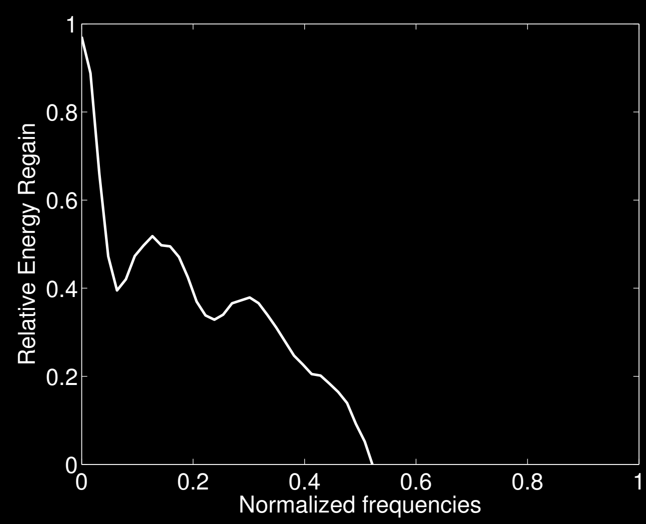


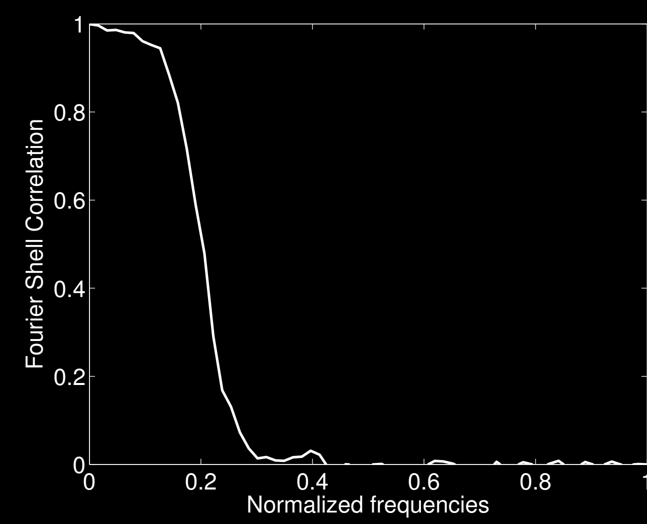


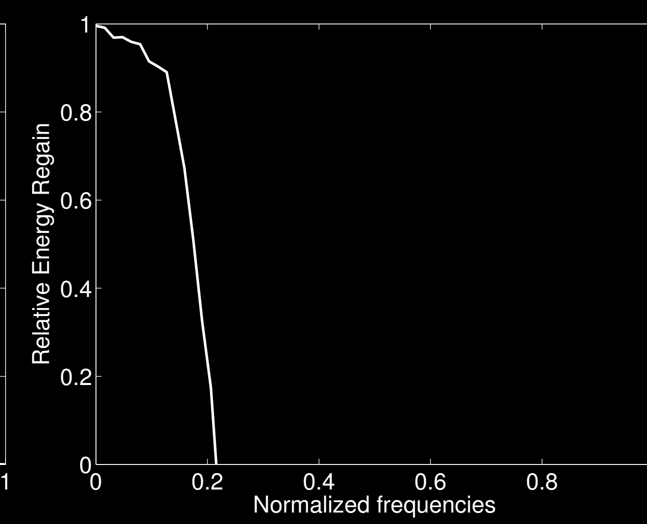






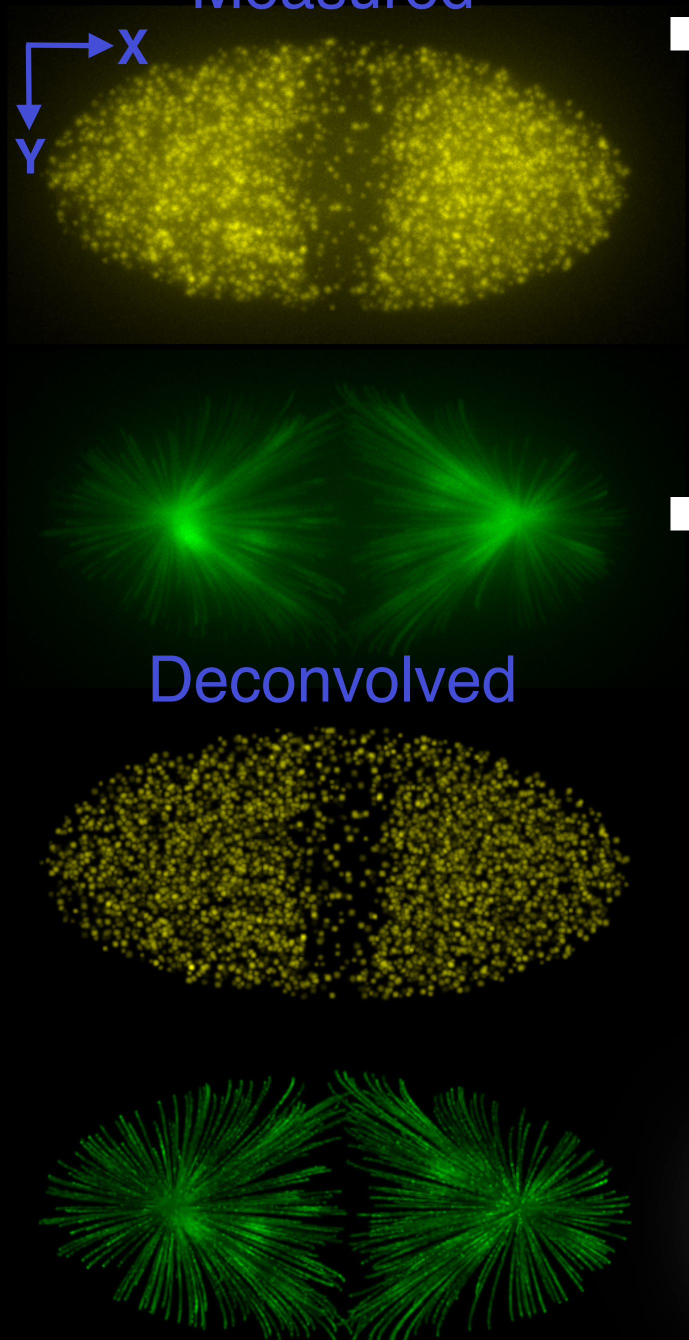






Summary of the challenge

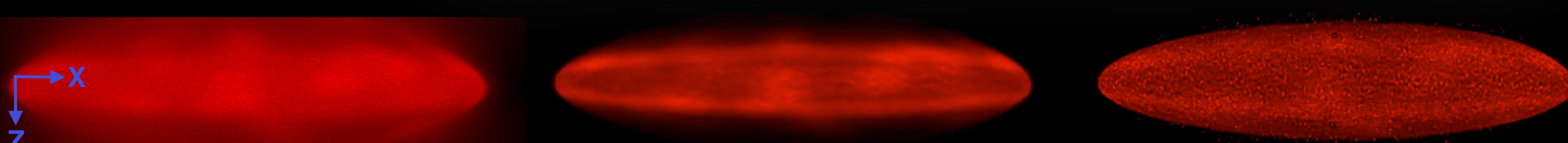
Measured



- This year's awardees (SPS-sponsored prizes):
  1. Ferréol Soulez, Lyon University ($500)
  2. David Biggs, KB Imaging Solutions ($300)
  3. Hiep Luong, Gent University ($200)
- Next edition:
  - Online submission system to reopen soon
  - Take up the challenge & submit your result!
  - Best entries will win ISBI 2014 travel grants!
  - Visit our website for updates:

2014

bigwww.epfl.ch/deconvolution/challenge



Measured Deconvolved