Syllabus of BioTCC 2018 - please check again for **BioTCC 2019** in January 2019

IST Austria Graduate School

Biology Track Core Course 2018

Content

1. Important dates

Lectures:
Start: Mon, 26-Feb-2018 (08:45 - 10:00), Mondi 3
End: Wed, 20-Jun-2018 (08:45 - 10:00), Mondi 3

Recitations:
Start: Mon, 05-Mar-2018, (10:15-11:00), Mondi 3

Proposal deadline:
June 29th

Final grade:
July 16th

2. Course description

Every big biological problem has a structural, mechanical, evolutionary, genetic and population side to it. The goal of the biology core course is to illustrate that fundamental biological problems and phenomena can be approached from vastly different angles.

In this course we will bridge different areas in biology to show students how fundamental biological problems and phenomena can be approached from different perspectives.

This year we will discuss one broad topic: **Spatiotemporal organization.** The instructors will provide a list of papers to be studied, typically in the form of a review paper or something equivalent.

3. Grades

The final grade is given based on participation in class (50 %, presentation + discussions) and the written proposal (50%).

The **presentation** is given by two students who should present the paper in about 60 min. The presentation should be an interactive presentation and include a discussion: focus on critical reading, formulating questions/hypotheses and follow up experiments.

The **written proposal** should be about 3-4 pages long on any topic regarding spatiotemporal organization in biology within the expertise of the teaching faculty. It should include, background, aims, methods and significance.

Deadline for the written proposal is June 29th, final grade is given on July 16th. Grade and proposal can be discussed with the instructors personally until end of July.

4. Course instructors & TAs

	Instructor	**TA**
1	Nick Barton	Daria Shipilina
2	Eva Benkova	Juan Carlos Montesinos
3	Johann Danzl	Sven Truckenbrodt

4	Edouard Hannezo	
5	Carl-Philipp Heisenberg	Shayan Shami Pour
6	Martin Loose	Urban Bezeljak Paulo Caldas
7	Florian Schur	

5. Students

	Student
1	Bettina Zens
2	Jakub Hajny
3	**Louise Arathoon**
4	Kristina Lukic
5	Lukas Hörmayer
6	Michael Riepl
7	Michaela Misova
8	Nikola Canigova
9	Vladyslav Kravchuk
10	XiXi Zhang

6. Schedule

Lecture	Date	Instructor	Topic	Students presenting
1	26.2.	**All**	Welcome	
2	28.2.	**Nick Barton**	Spatial patterns in populations: adaptation and speciation	
3	5.3.	**Nick Barton**	Student presentations/Problems class	Jakub & Louise

4	7.3.	**Nick Barton**	Spatial patterns in populations: Invasions	
5	12.3.	**Nick Barton**	Student presentations/Problems class	Bettina & Lukas
6	14.3.	**Eva Benkova**	Principles of plant body architecture establishment	
7	19.3.	**Eva Benkova**	Student presentations/Problems class	Kristina & Vladyslav
8	21.3.	**Edouard Hannezo**	Design principles of genetic and biochemical oscillators	
9	26.3.	**Edouard Hannezo**	Student presentations	Michael & Nika
10	28.3.	**Edouard Hannezo**	Models of wave propagation and pattern formation	
11	16.4.	**Edouard Hannezo**	Student presentations	Xixi & Michaela
12	18.4.	**Carl-Philipp Heisenberg**	Force generation and transduction in cell and tissue morphogenesis	
13	23.4.	**Carl-Philipp Heisenberg**	Student presentations	Lukas & Jakub
14	25.4.	**Carl-Philipp Heisenberg**	Mechanosensation in cell division, extrusion and specification	
15	30.4.	**Carl-Philipp Heisenberg**	Student presentations	Vladyslav & Michaela
16	2.5.	**Eva Benkova**	Interpretation of auxin morphogen gradients	
17	7.5.	**Eva Benkova**	Student presentations/Problems class	Louise & Nika
18	9.5.	**Johann Danzl**	Introduction: spatial organization of cells and tools	
19	14.5.	**Johann Danzl**	Student presentations	Louise & Kristina
20	16.5.	**Johann Danzl**	Introduction: the synapse as model for nanoarchitecture	
21	23.5.	**Johann Danzl**	Student presentations	Bettina & Michael
22	28.5.	**Martin**	Intro: Mechanisms of intracellular organization	

		Loose		
24	30.5.	**Martin Loose**	Student presentation: Cytokinesis	Michaela & Jakub
23	4.6.	**Martin Loose**	Student presentation: Reaction-diffusion mechanisms	Xixi & Nika
25	6.6.	**Martin Loose**	Student presentation: Phase-separation	Lukas & xixi
26	11.6.	**Florian Schur**	Spatial and temporal regulation of directed intra- and extracellular transport	
27	13.6.	**Florian Schur**	Student presentation: Time-scales of coated vesicle formation (intracellular transport)	Kristina & Michael
28	18.6.	**Florian Schur**	Student presentation: Dynamics in virus assembly and maturation (extracellular transport)	Bettina & Vladyslav
29	20.6.	**Final presentation**		

7. Lecture content

Course Material

Course material such as large data files and documents can be found using **this link**.

February 26: Welcome (all instructors)

Instructors will give an introduce the content and scope of the course.

February 28: Nick Barton: Spatial patterns in adaptation and speciation

Populations often show striking spatial and temporal patterns: cicadas with prime-numbered life cycles, or sharp boundaries between areas where butterflies share different wing patterns. These are interesting in themselves, but also practically important, for understanding epidemics and invasive species, and important for evolution, in relation to local adaptation and speciation.

In these sessions, we will focus on the interplay between selection and gene flow, and how this can be modelled by diffusion. The same processes will recur later, in modelling development and intracellular organisation.

General background:
Barton et al., 2007 *Evolution*, pp. 496-505. Cold Spring Harbor Press.

March 5: Nick Barton

Student presentations:
Rosser N., Dasmahapatra K. K., Mallet J., 2014 Stable Heliconius butterfly hybrid zones are correlated with a local rainfall peak at the edge of the Amazon basin. Evolution **68**: 3470–3484.

Linnen C. R., Hoekstra H. E., 2009 Measuring Natural Selection on Genotypes and Phenotypes in the Wild. Cold Spring Harbor Symp. Quant. Biol. **74**: 155–168.

Problems class: Simulating clines and hybrid zones

March 7: Nick Barton: Invasions of genes and species

March 12: Nick Barton

Student presentations:
Schmidt et al., 2017 Local introduction and heterogeneous spatial spread of dengue-suppressing Wolbachia through an urban population of Aedes aegypti. PLoS Biol 15: e2001894.

McCaskill J. S., Bauer G. J., 1993 Images of evolution: Origin of spontaneous RNA replication waves. Proceedings of the National Academy of Sciences of the USA 90: 4191–4195.

Background review

Gandon S., Day T., Metcalf C. J. E., Grenfell B. T., 2016 Forecasting Epidemiological and Evolutionary Dynamics of Infectious Diseases. Trends Ecol. Evol. 31: 776–788.

Problems class: Simulating the spread of a favourable allele

March 14: Eva Benkova: Principles of plant body architecture establishment

Plants are sessile organisms permanently attached to one location. Throughout evolution, this lack of mobility has been compensated by a unique survival strategy – an exceptional developmental flexibility of the plant body. Plants are able to rapidly modulate their growth and whole body architecture in order to efficiently use local resources and to adapt to fluctuating

environmental conditions. In this session, we will focus on the basic principles of plant body architecture establishment.

March 19: Eva Benkova

Students presentation:
Rules and Self-Organizing Properties of Post-embryonic Plant Organ Cell Division Patterns.
von Wangenheim D, Fangerau J, Schmitz A, Smith RS, Leitte H, Stelzer EH, **Maizel A**.
Curr Biol. 2016 Feb 22;26(4):439-49. doi: 10.1016/j.cub.2015.12.047.

Local, efflux-dependent **auxin** gradients as a common module for plant organ formation.
Benková E, Michniewicz M, Sauer M, Teichmann T, Seifertová D, Jürgens G, Friml J.
Cell. 2003 Nov 26;115(5):591-602.

Background review:
As above, so below: Auxin's role in lateral organ development.Taylor-Teeples M, Lanctot A, Nemhauser JL.
Dev Biol. 2016 Nov 1;419(1):156-164.

March 21: Edouard Hannezo: Design principles of biochemical and genetic oscillators

Introduction: How do cells regulate complex temporal oscillations?

Are there generic models to understand genetic and biochemical oscillations?

- Cell cycle regulation
- Circadian rhythm
- Segmentation clock

March 26: Edouard Hannezo

Students presentation:
Analysis of a generic model of eukaryotic cell-cycle regulation.
Csikász-Nagy, Attila, et al. *Biophysical journal* 90.12 (2006): 4361-4379.

Modeling the cell cycle: why do certain circuits oscillate?.
Ferrell, J. E., Tsai, T. Y. C., & Yang, Q. (2011). *Cell*, *144*(6), 874-885.

Background review:
Design principles of biochemical oscillators.
Novák, Béla, and John J. Tyson. *Nature reviews Molecular cell biology* 9.12 (2008): 981.

March 28: Edouard Hannezo: Models of wave propagation and pattern formation

Introduction: Precise spatio-temporal patterning must occur at every stage of morphogenesis

Are there generic models to understand these patterns in tissues?

- Action potential propagation
- Turing patterns
- Sequential patterning

April 16: Edouard Hannezo

Students presentation:

Notch-mediated lateral inhibition regulates proneural wave propagation when combined with EGF-mediated reaction diffusion.
Sato, M., Yasugi, T., Minami, Y., Miura, T., & Nagayama, M. (2016). *Proceedings of the National Academy of Sciences*, *113*(35), E5153-E5162.

Interactions between zebrafish pigment cells responsible for the generation of Turing patterns.
Nakamasu, A., Takahashi, G., Kanbe, A., & Kondo, S. (2009). Proceedings of the National Academy of Sciences, 106(21), 8429-8434.

Background review:

Positional information and reaction-diffusion: two big ideas in developmental biology combine.
Green, J. B., & Sharpe, J. (2015). *Development*, *142*(7), 1203-1211.

April 18: Carl-Philipp Heisenberg: Force generation and transduction in cell and tissue morphogenesis

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April 23: Carl-Philipp Heisenberg

Students presentation:

Tensile forces govern germ-layer organization in zebrafish

Krieg M, Arboleda-Estudillo Y, Puech PH, Käfer J, Graner F, Müller DJ, Heisenberg CP

Forces for Morphogenesis Investigated with Laser Microsurgery and Quantitative Modeling
M. Shane Hutson, Yoichiro Tokutake, Ming-Shien Chang, James W. Bloor,Stephanos Venakides, Daniel P. Kiehart, Glenn S. Edwards

Background review:

Forces in Tissue Morphogenesis and Patterning
Carl-Philipp Heisenberg and Yohanns Bellaı̈che

April 25: Carl-Philipp Heisenberg: Mechanosensation in cell division, extrusion and specification

April 30: Carl-Philipp Heisenberg

Students presentation:

Mechanical stretch triggers rapid epithelial cell division through Piezo1

S. A. Gudipaty1, J. Lindblom , P. D. Loftus , M. J. Redd , K. Edes , C. F. Davey , V. Krishnegowda & J. Rosenblatt

Role of YAP/TAZ in mechanotransduction

Sirio Dupont, Leonardo Morsut, Mariaceleste Aragona , Elena Enzo , Stefano Giulitti , Michelangelo Cordenonsi , Francesca Zanconato , Jimmy Le Digabel , Mattia Forcato , Silvio Bicciato , Nicola Elvassore & Stefano Piccolo

Background review:

Multiscale force sensing in development

Petridou NI, Spiró Z, Heisenberg CP

May 2: Eva Benkova: Interpretation of auxin morphogen gradients

Plant hormones represent important endogenous regulators of plant development that allow plants to rapidly adjust their growth to environmental signals. Among them the hormone auxin is essential to control plant growth and development including early embryogenesis and postembryonic organogenic processes, such as root branching, phyllotaxis, shoot and root apical meristem activity. In this session, we will focus on the common aspects of molecular mechanisms underlying auxin regulation of various plant developmental processes.

May 7: Eva Benkova

Students presentation:

MONOPTEROS controls embryonic root initiation by regulating a mobile transcription factor.

Schlereth A, Möller B, Liu W, Kientz M, Flipse J, Rademacher EH, Schmid M, Jürgens G, Weijers D. Nature. 2010 Apr 8;464(7290):913-6

TIR1/AFB-Aux/IAA auxin perception mediates rapid cell wall acidification and growth of Arabidopsis hypocotyls. Fendrych M, Leung J, Friml J. Elife. 2016 Sep 14;

Background review:

Auxin Signaling. Leyser O. Plant Physiol. 2018 Jan;176(1):465-479

May 9: Johann Danzl

Cells are composed of a diverse set of molecules, including proteins, nucleic acids, lipids, and a wide range of small molecule metabolites, that act together to enable the functions that characterize them as living systems.

A cell operates far from thermal equilibrium, such that its constituents are organized in highly elaborate structures. Finding out how the cell is organized spatially and how the interaction with the environment shapes the molecular architecture of the cell is a central requirement for gaining a mechanistic understanding of biological processes.

Our discussion will bridge from the tissue level of cell-cell contacts to the level of macromolecular complexes in subcellular compartments. We will explore chemical synapses as a highly specialized structure and one of the best studied examples of vesicle trafficking and release. We will also put an emphasis on the methodology to unravel spatial organization with molecular specificity, in particular advanced light microscopy methods.

Questions to be addressed:
How can we analyse single cells?
What do analyses on the DNA, RNA, and protein level tell us?
How can we analyse single cells while preserving cellular and tissue spatial context?
How does diffraction-unlimited optical imaging increase spatial resolution into the nanometer range?

Background reading on diffraction-unlimited optical imaging:
Fluorescence nanoscopy in cell biology
Sahl, S. J., S. W. Hell, S. Jakobs, Nature Rev. Mol. Cell Biol. 18, 685-701 (2016)

Breaking the diffraction barrier: Super-resolution imaging of cells
B. Huang, H. Babcock, X. Zhuang, Cell 143 1047-1058 (2010)

May 14: Johann Danzl

Students presentation:
A subcellular map of the human proteome
Thul *et al*., Science 10.1126 (2017)
A rather comprehensive workup of subcellular protein distribution. Raises interesting questions of what type of information one can obtain from such proteomics scale in situ experiments.

Nanoscale architecture of cadherin-based cell adhesions:
Berocchi *et al*., Nature Cell Biology 19, 28 (2017)

Bridging the scale from cell-cell contacts in the tissue and their architecture to biochemmically reduced reconstitution experiments.

May 16: Johann Danzl

Introduction: the synapse as a model system for nanoscale protein architecture and membrane vesicle fusion

Presynaptic boutons contain a well-studied machinery for sensing of a release signal (the action potential), its relay via a second messenger (Ca2+), and vesicle release. Many of the mechanisms are conserved in other vesicle/membrane fusion events, such that the synapse can serve as a valuable didactic example for a much broader class of cellular events beyond neurotransmitter release.

Questions to be addressed:
What are the peculiar organizational principles of neurons?
How are cell-cell contacts arranged here?
What can we learn about the vesicle fusion and release machinery?

May 23: Johann Danzl

Students presentation:
Composition of isolated synaptic boutons reveals the amounts of vesicle trafficking proteins
Wilhelm BG, Mandad S, Truckenbrodt S, Kröhnert K, Schäfer C, Rammner B, Koo SJ, Claßen GA, Krauss M, Haucke V, Urlaub H, Rizzoli SO.
Science 344, 1023-8 (2014).
Molecular composition of a subcellular compartment derived from average data and condensed into a bioinformatics-based model. Gives an impressive account of how one can think of the molecular makeup of cells.

A trans-synaptic nanocolumn aligns neurotransmitter release to receptors
Tang *et al*., Nature 536, 210 (2016)
Imaging-based analysis of how molecules are organized across the cell-cell contact at synapses with very interesting functional implications for the nanoscale relative spatial arrangement of release sites (signal generation) and receptors (signal detection) in view of fast diffusion and signal deactivation..

Background reading on diffraction-unlimited optical imaging:
Seeing the forest tree by tree: super-resolution light microscopy meets the neurosciences
Maglione and Sigrist, Nature Neuroscience 16, 790 (2013).

Superresolution imaging of chemical synapses in the brain.
Dani et al., Neuron 68(5), 843 (2010).

May 28: Martin Loose - Mechanisms of intracellular organization

Introduction: What are the molecular mechanisms of intracellular organization?

In general, biological structures can emerge due to two fundamentally different process, first via self-assembly, which describes equilibrium structures and second, via self-organization, which corresponds to self-organized structures that exist in a dynamic steady state. In this introductory lecture, we will discuss the differences between these two concepts using two highly complex biological structures as example: the bacteriophage T4 and the mitotic spindle. Furthermore, we will introduce e the mechanisms available to cells to organize intracellular space, namely reaction-diffusion processes, biopolymers and phase separation. Using these concepts, we will discuss the following questions: What are advantages and disadvantages of self-assembled versus self-organized structures? Why do cells use self-assembly? Why self-organization?

Reviews for general background:
Karsenti, E. (2008). Self-organization in cell biology: a brief history. Nature Reviews Molecular Cell Biology, 9(3), 255–262. http://doi.org/10.1038/nrm2357

Misteli, T. (2001). The concept of self-organization in cellular architecture. The Journal of Cell Biology, 155(2), 181–186. http://doi.org/10.1083/jcb.200108110

May 30: Martin Loose - Mechanics of the cytoskeleton - cytokinesis

E. coli and *S. pombe* both have rod-shaped cells that divide by symmetric division. The aim of this lecture is to get to know the different biological structures these organisms employ to perform cytokinesis. Furthermore, we will discuss advantages, disadvantages, gains and tradeoffs of two different experimental approaches to understand intracellular assemblies: fluorescence versus electron microscopy. The aim of this lecture is also to discuss the current challenges in biology to visualize the architecture and dynamics of the intracellular space.

Questions to address:

1. What is the differences and similarities between cytokinesis in *E. coli* and *S. pombe*?
2. What do we learn from *in vitro* and *in vivo* experiments?
3. What do we learn from Cryo-ET and SMLM?

Students presentation:

I. Cytokinesis by the actin ring
McDonald, N. A., Lind, A. L., Smith, S. E., Li, R., & Gould, K. L. (2017). Nanoscale architecture of the Schizosaccharomyces pombe contractile ring. eLife, 6, e28865. http://doi.org/10.7554/eLife.28865

Swulius, M. T., Nguyen, L. T., Ladinsky, M. S., Ortega, D. R., Aich, S., Mishra, M., & Jensen, G. J. (2018). Structure of the fission yeast actomyosin ring during constriction. Proceedings of the National Academy of Sciences, 94, 201711218. http://doi.org/10.1073/pnas.1711218115

II. Cytokinesis by the FtsZ ring
Loose, M., & Mitchison, T. J. (2014). The bacterial cell division proteins FtsA and FtsZ self-organize into dynamic cytoskeletal patterns. Nat Cell Biol, 16(1), 38–46. http://doi.org/10.1038/ncb2885

Yang, X., Lyu, Z., Miguel, A., McQuillen, R., Huang, K. C., & Xiao, J. (2017). GTPase activity-coupled treadmilling of the bacterial tubulin FtsZ organizes septal cell wall synthesis. Science, 355(6326), 744–747. http://doi.org/10.1126/science.aak9995

Review:
T. D. Pollard (2017). Nine unanswered questions about cytokinesis. The Journal of Cell Biology, jcb.201612068. http://doi.org/10.1083/jcb.201612068

June 4: Martin Loose - Reaction-diffusion mechanisms to organize cells

The unicellular organism S. cerevisae is able to polarize in the absence of any external spatial cue. In this lecture, we will discuss two different mechanisms giving rise to cellular polarization: first, directed transport and second, a reaction-diffusion based process. We will elaborate on the properties of these fundamentally different mechanisms and how they contribute to polarization of the cell. We will also address the general requirements for biochemical circuits to locally amplify biological signals, how to, break intracellular symmetry and how to this spatial information can be maintained over long times.

Students presentation:
Wedlich-Soldner, R., Altschuler, S., Wu, L., & Li, R. (2003). Spontaneous cell polarization through actomyosin-based delivery of the Cdc42 GTPase. Science, 299(5610), 1231–1235. http://doi.org/10.1126/science.1080944

Altschuler, S. J., Angenent, S. B., Wang, Y., & Wu, L. F. (2008). On the spontaneous emergence of cell polarity. Nature, 454(7206), 886–889. http://doi.org/10.1038/nature07119

Review:
Chiou, J.-G., Balasubramanian, M. K., & Lew, D. J. (2017). Cell Polarity in Yeast. Annu Rev Cell Dev Biol, 33(1), 77–101. http://doi.org/10.1146/annurev-cellbio-100616-060856

June 6: Martin Loose - Phase-separation in the cytoplasm

In the last couple of years it has become clear that the cytoplasm not necessarily represents one continuous phase, but that the cytoplasm is organized by biomolecular condensates that give rise to liquid-liquid phase separation in the cell. In this lecture, we will discuss the principle of principle liquid-liquid phase separation, the molecular requirements, the regulation of phase separation as well as the function of those condensates. Finally , we will also address the negative consequences of a misregulation of phase separation for the cell.

Research papers:

Brangwynne, C. P., Eckmann, C. R., Courson, D. S., Rybarska, A., Hoege, C., Gharakhani, J., et al. (2009). Germline P granules are liquid droplets that localize by controlled dissolution/condensation. Science, 324(5935), 1729–1732. http://doi.org/10.1126/science.1172046

Su, X., Ditlev, J. A., Hui, E., Xing, W., Banjade, S., Okrut, J., et al. (2016). Phase separation of signaling molecules promotes T cell receptor signal transduction. Science, 352(6285), 595–599. http://doi.org/10.1126/science.aad9964

Review:

Banani, S. F., Lee, H. O., Hyman, A. A., & Rosen, M. K. (2017). Biomolecular condensates: organizers of cellular biochemistry. Nature Reviews Molecular Cell Biology, 18(5), 285–298. http://doi.org/10.1038/nrm.2017.7

June 11: Florian Schur - Spatio-temporal regulation of intra/extracellular transport

Introduction: Coated Vesicles and enveloped Viruses

Coated vesicles and enveloped viruses can be considered to perform homologous but opposite processes. Both are higher-order structures, assembled to transport their selectively recruited cargo to distinct target locations.

Hence, vesicles and viruses are required for the spatial organization and distribution of components within and across cells. In order to do so efficiently, this requires another level of complexity on the temporal level, where vesicles and viruses need to at one point prime themselves for fusion with their target membranes (e.g. a organelle or cell).

In two sessions we will first focus on how coated vesicles are formed. In the second part we will take a look at a specific example of virus maturation. These two examples are well suited to exemplify the time scales that one can face in experimental biology and what kind of experimental tools one has to study these or similar events.

General concepts & mechanisms

- Higher-order protein assemblies: coated vesicles and enveloped viruses
- General concepts of intracellular vesicular transport
- Virus assembly, budding and maturation
- Protein cages

June 13: Florian Schur - Time scales of coated vesicle formation

Questions to address:

- How does clathrin-mediated endocytosis proceed?
- What direct and indirect measures do we have to observe short-lived dynamic events?
- What do we learn from studies that allow us to decompose such short-lived events?

Student presentations:
Cocucci, E., Aguet, F., Boulant, S. & Kirchhausen, T. The First Five Seconds in the Life of a Clathrin-Coated Pit. *Cell* **150,** 495–507 (2012). doi:10.1016/J.CELL.2012.05.047

Kukulski, W., Schorb, M., Kaksonen, M. & Briggs, J. A. G. Plasma Membrane Reshaping during Endocytosis Is Revealed by Time-Resolved Electron Tomography. *Cell* **150,** 508–520 (2012). doi:10.1016/J.CELL.2012.05.046

Background reviews:
Kirchhausen, T., Owen, D. & Harrison, S. C. Molecular structure, function, and dynamics of clathrin-mediated membrane traffic. Cold Spring Harb. Perspect. Biol. 6, a016725 (2014). doi:10.1101/cshperspect.a016725

Faini, M., Beck, R., Wieland, F. T. & Briggs, J. A. G. Vesicle coats: structure, function, and general principles of assembly. Trends Cell Biol. 23, 279–288 (2013). doi:10.1016/J.TCB.2013.01.005

June 18: Florian Schur - Dynamics in virus assembly and maturation

Questions to address:
- How does retroviral assembly and maturation proceed?
- How can a virus regulate the temporal sequence of assembly and maturation?
- Why do retroviruses require a maturation step?

Student presentations:
Monroe, E. B., Kang, S., Kyere, S. K., Li, R. & Prevelige Jr., P. E. Hydrogen/deuterium exchange analysis of HIV-1 capsid assembly and maturation. *Structure* 18, 1483–1491 (2010). doi:10.1016/j.str.2010.08.016

Chojnacki, J., Staudt, T., Glass, B., Bingen, P., Engelhardt, J., Anders, M., Schneider, J.,
Müller, B., Hell, S. W. & Kräusslich, H.-G. Maturation-Dependent HIV-1 Surface Protein Redistribution Revealed by Fluorescence Nanoscopy. *Science (80-.).* **338,** 524–528 (2012)

Background reviews:
Mattei, S., Schur, F. K. & Briggs, J. A. Retrovirus maturation - An extraordinary structural transformation. *Curr. Opin. Virol.* 18, 27–35 (2016). doi:10.1016/j.coviro.2016.02.008

Freed, E. O. HIV-1 assembly, release and maturation. *Nat. Rev. Microbiol.* 13, 484–496 (2015). doi:10.1038/nrmicro3490
