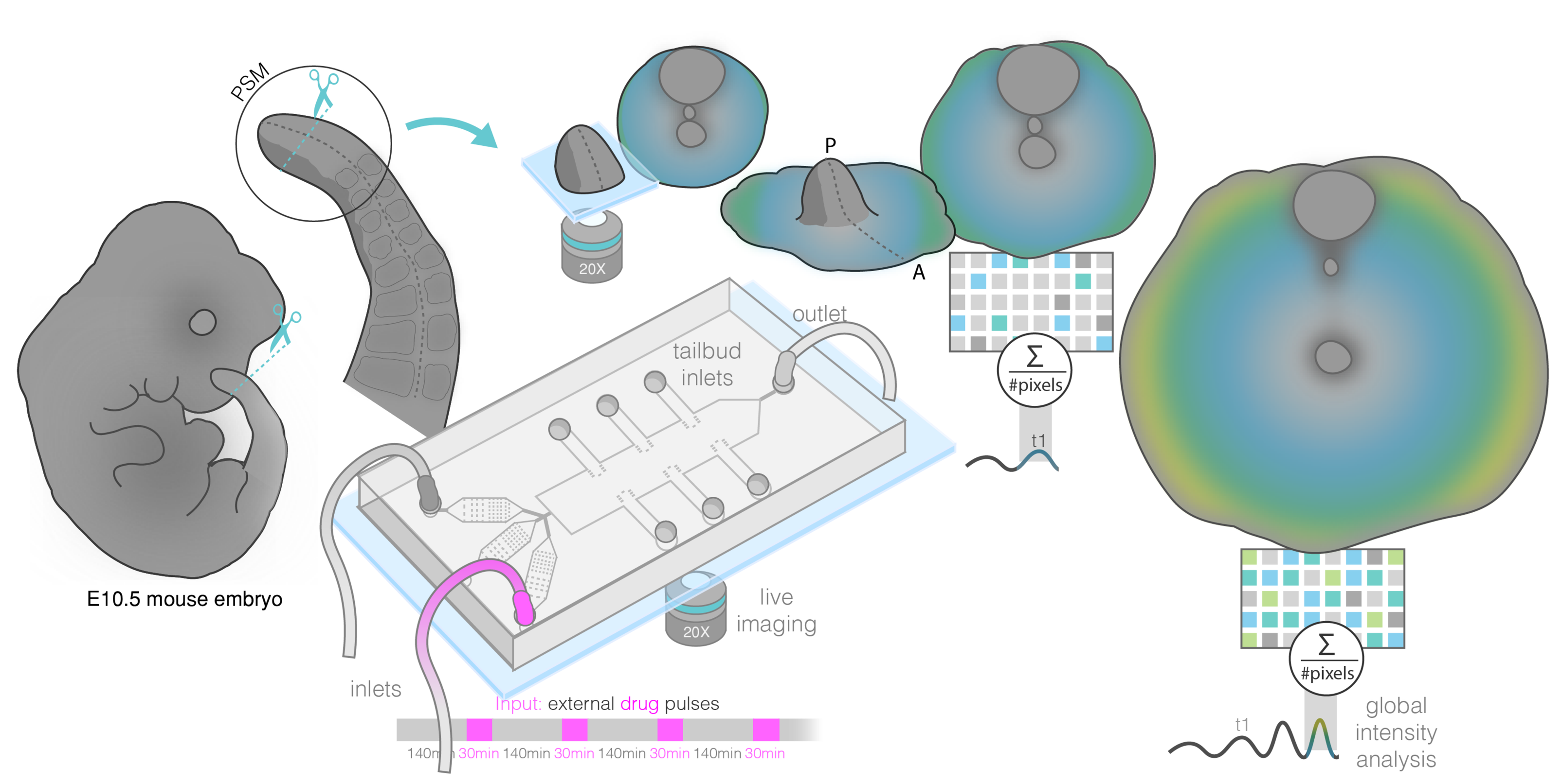
Entrainment response of the segmentation clock

EMBO | EMBL Symposium

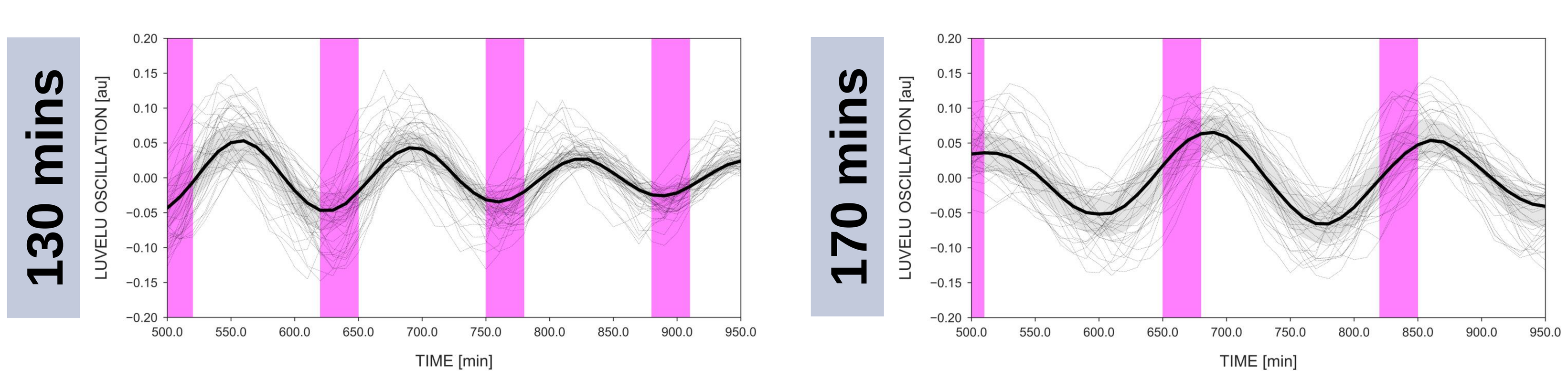
Biological oscillators: design, mechanism, function

We can entrain the segmentation clock

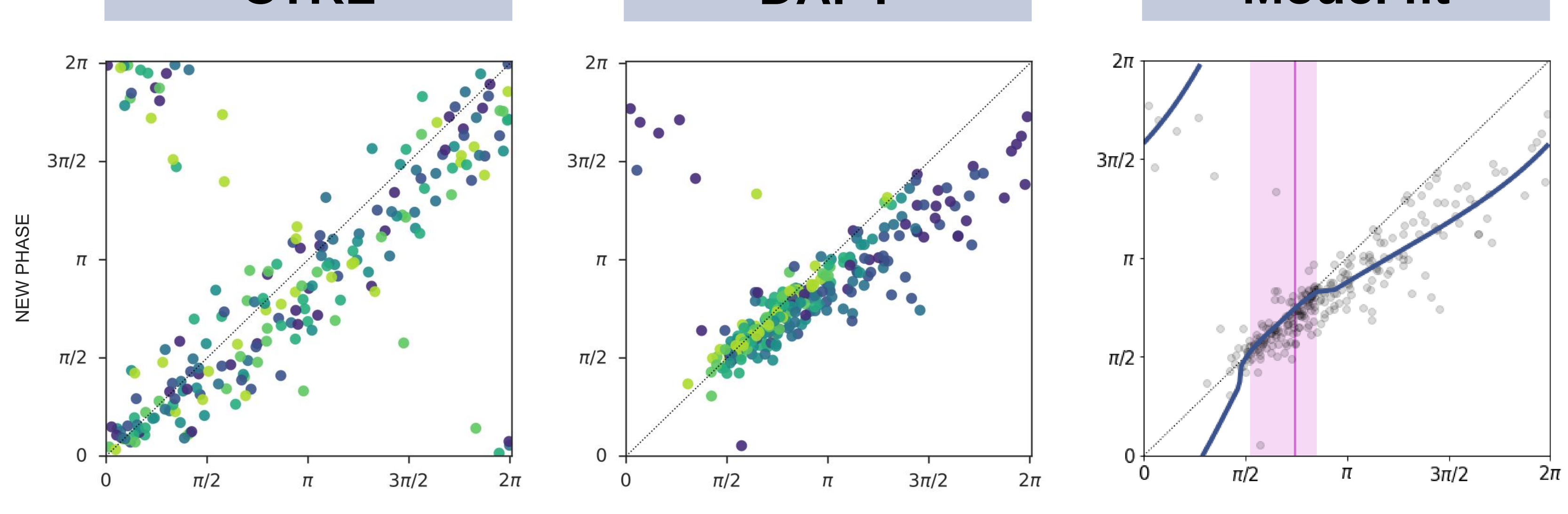


- Segmentation clock – a genetic oscillator ensemble that controls the periodic formation of somites in vertebrate embryos
- Averaging the oscillations over a 2D assay → coarse-grained description of the clock as a single oscillator
- Experimental setup allows to control the clock through entrainment with pulses of DAPT
- Entrained samples establish a fixed timing of oscillations relative to the pulses – period-locking and phase-locking

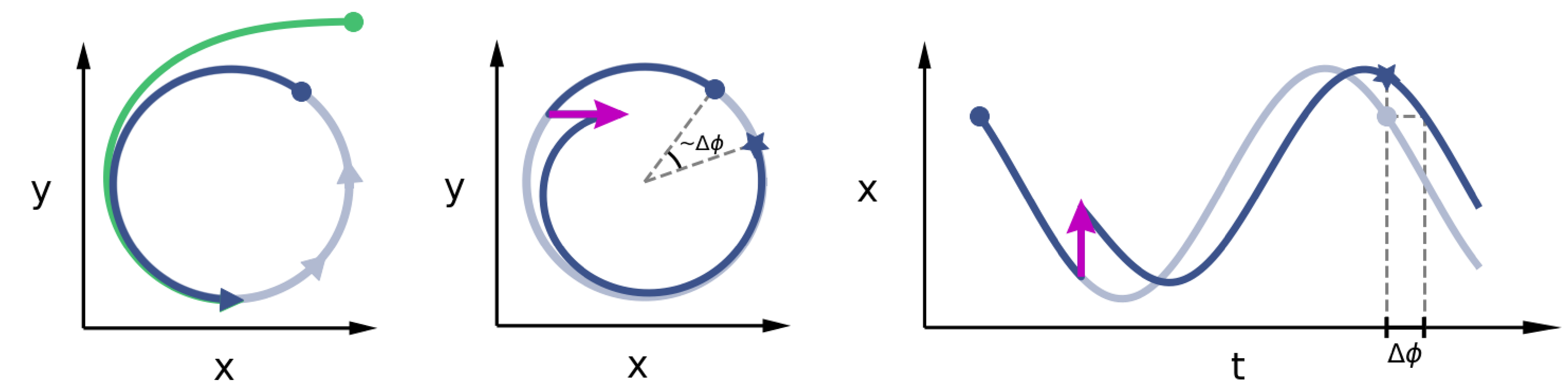
Movie



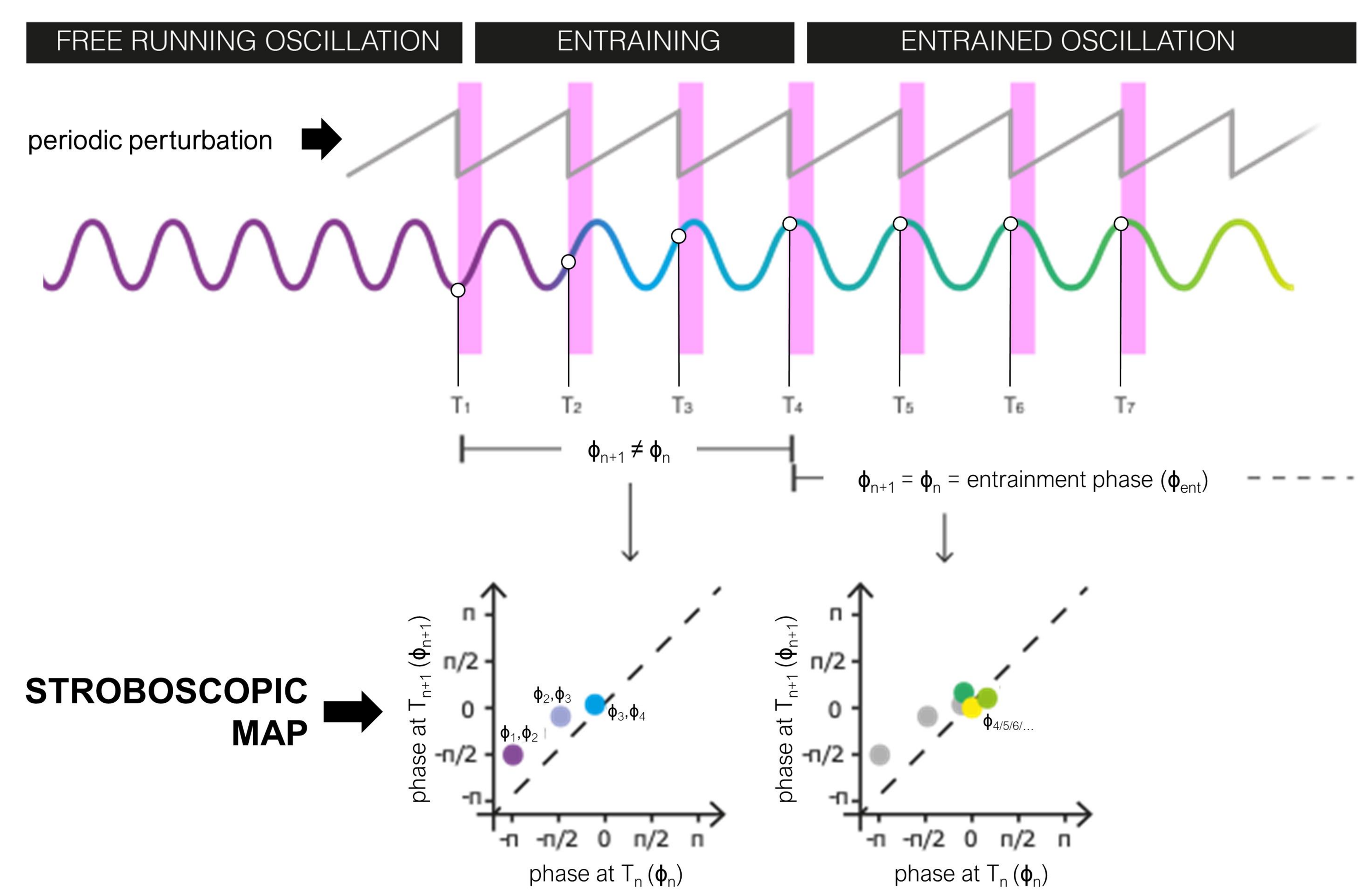
CTRL | DAPT | Model fit



Theoretical background



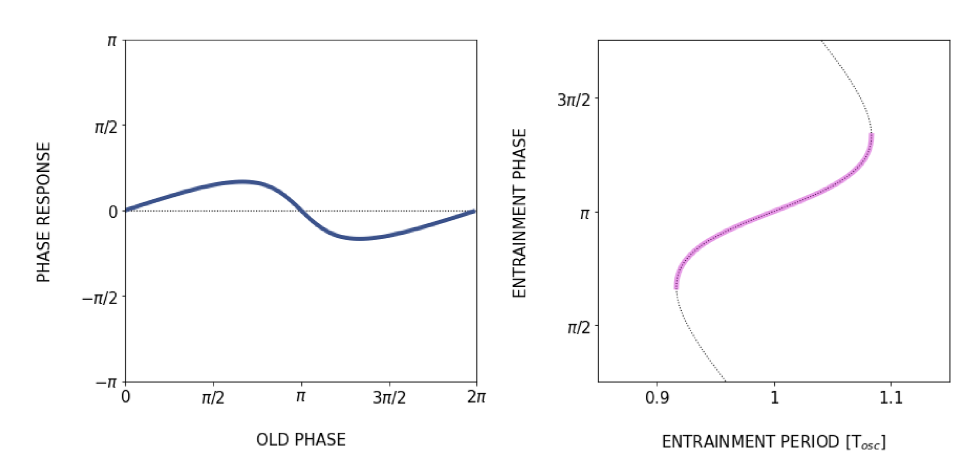
- Phase description of oscillators: phase is a measure of time along the cycle
- A perturbation can change the oscillator's phase → phase response
- Phase response creates the possibility of entrainment



Stroboscopic map allows to calculate the oscillator's phase response (PRC):

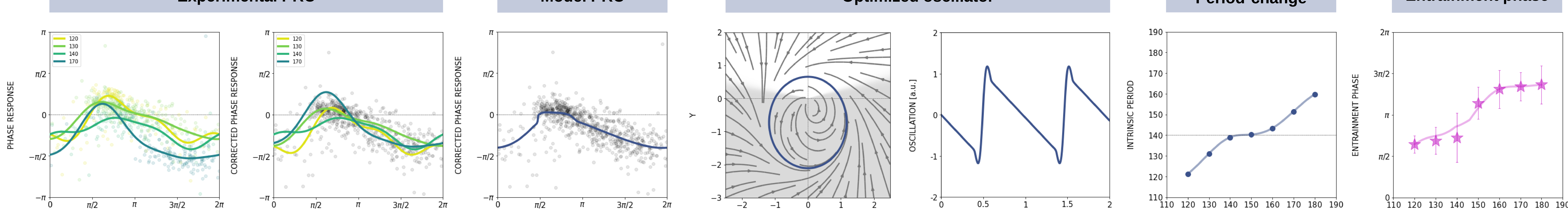
$$\phi_{n+1} = \left(\phi_n + PRC(\phi_n) + \frac{T_{zeit}}{T_{osc}} 2\pi \right) \bmod 2\pi$$

new phase | old phase | response to perturbation | detuning



- PRC of simple symmetric oscillators is sinusoidal
- Entrainment phase is an informative readout

Experimental PRC | Model PRC | Optimized oscillator | Period change | Entrainment phase



Modelling

- PRC is usually independent of the entrainment period
- We find a vertical shift in the PRCs for different entrainment periods – explained by an adjustment of the clock's intrinsic period during entrainment
- We construct a simple nonlinear model – an elliptic cycle with acceleration – and optimize the model phase response

Conclusions

- A single phase variable captures the dynamics of the multicellular segmentation oscillator system
- Highly asymmetric PRC – the system is naturally poised to slow down
- Analysis reveals a feedback within the clock allowing for period adjustments
- A systems-level, coarse-grained modelling uncovers the internal properties of the segmentation clock

Arnold tongue entrainment reveals dynamical principles of the embryonic segmentation clock

Paul Gerald Layague Sanchez, Victoria Mochulska, Christian Mauffette Denis, Gregor Mönke, Takehito Tomita, Nobuko Tsuchida-Straeten, Yvonne Petersen, Katharina F. Sonnen, Paul François, Alexander Aulehla (2021)

Full text