Evolutionary simulations to determine the human circadian period using an extended sleep-wake model

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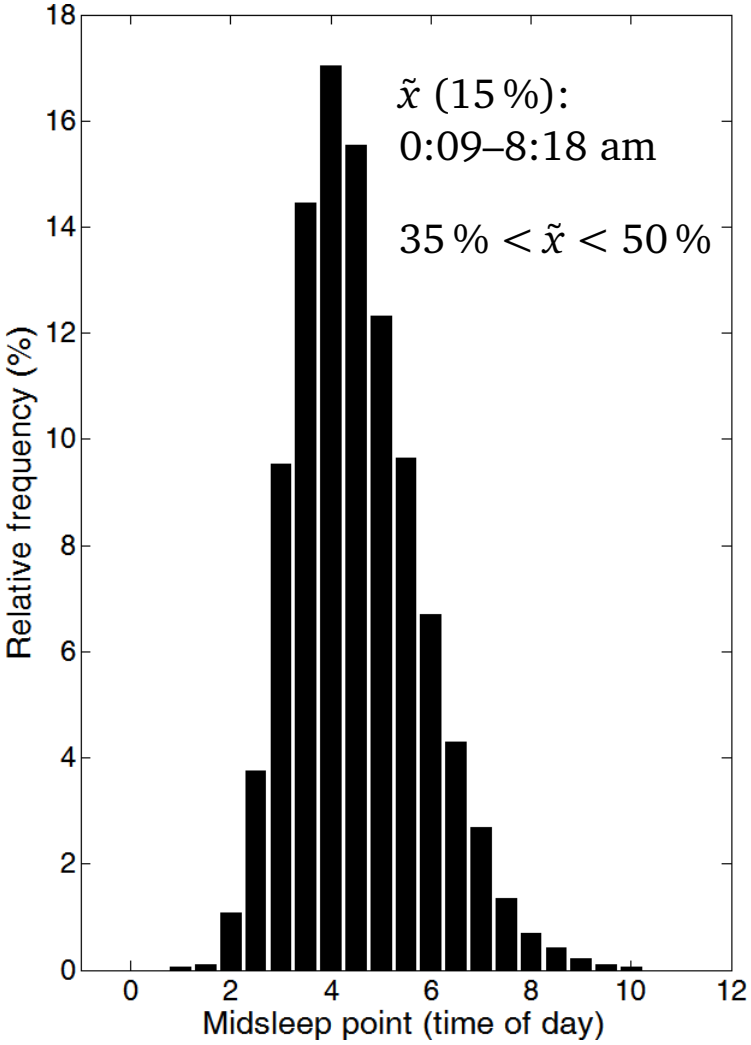
Motivation

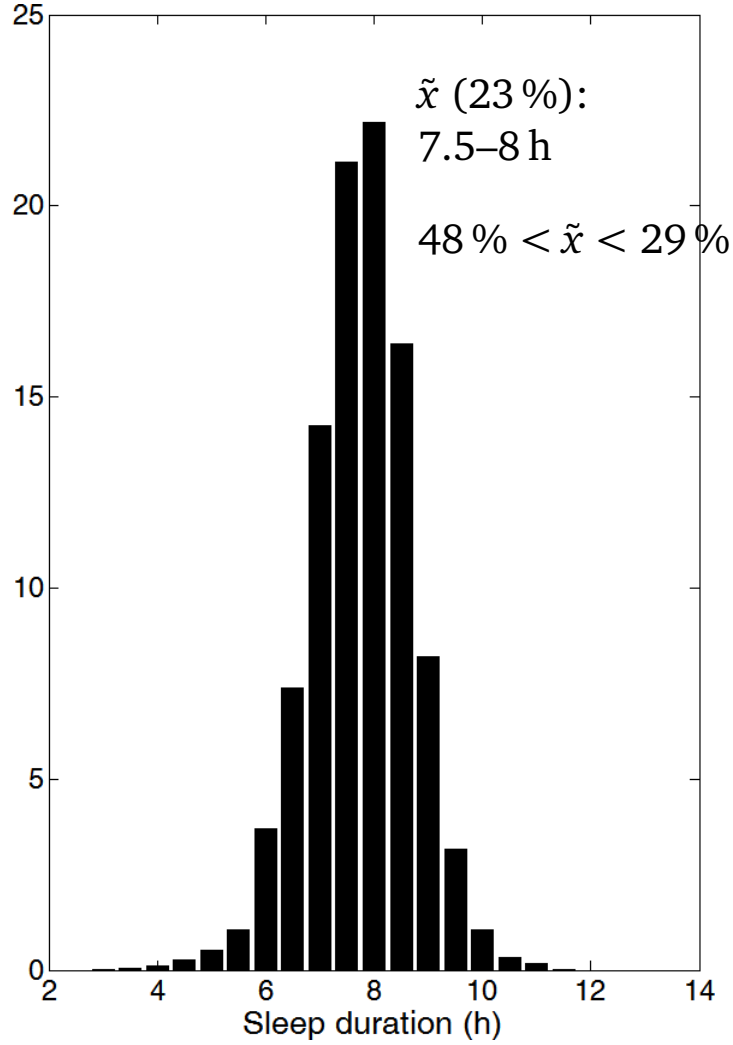
Sleep-wake behaviour

Different habits regarding sleep onset, wake up, sleep duration . . . referred to as *chronotype*.

Chronotypes

Survey over 55 000 Central Europeans:





cf. [Roenneberg et al. 2007]

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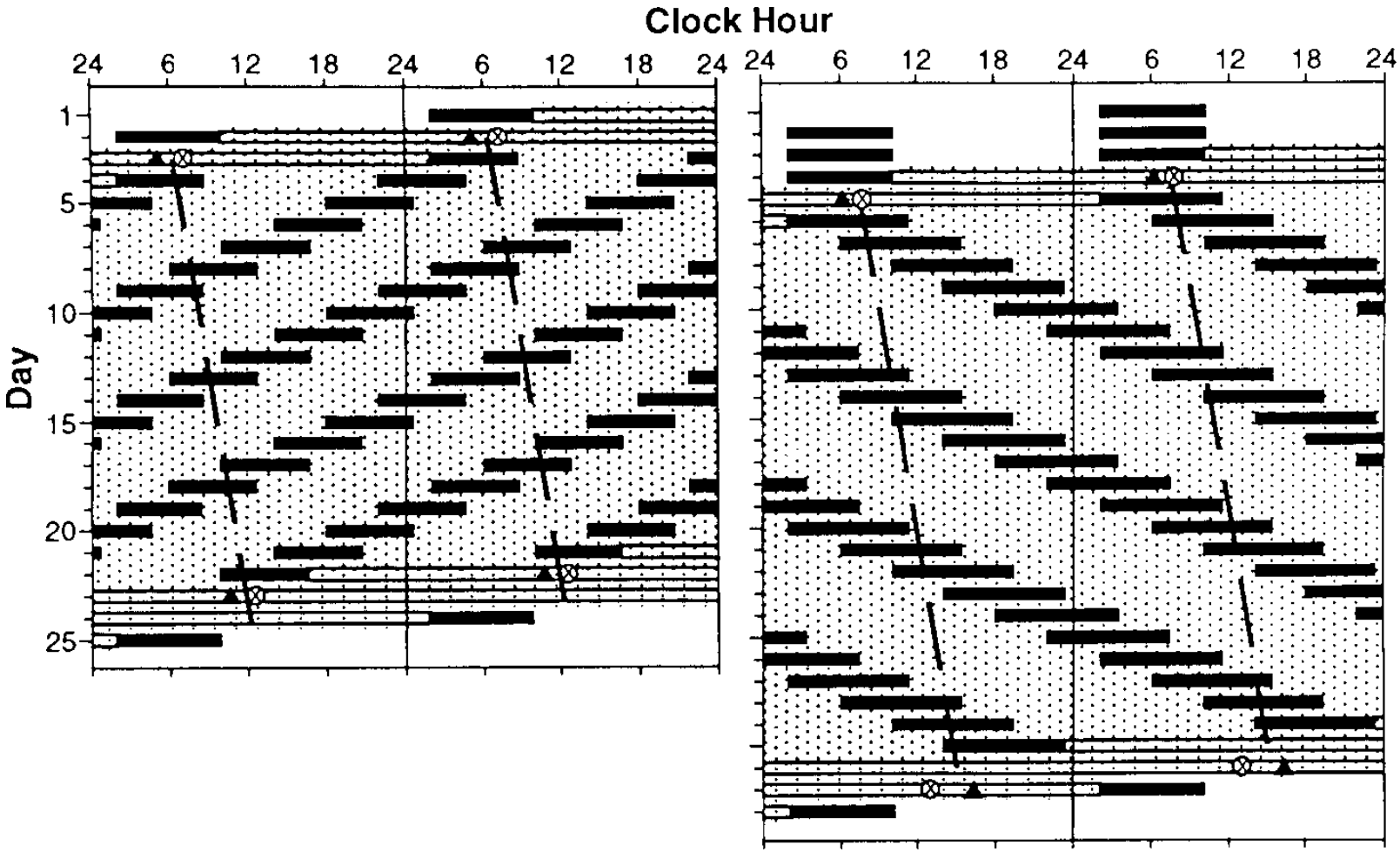
Chronobiology

Different characteristics of the human inner clock, the so called *circadian* (i. e. near 24-h) *rhythm*.

Forced desynchrony experiments

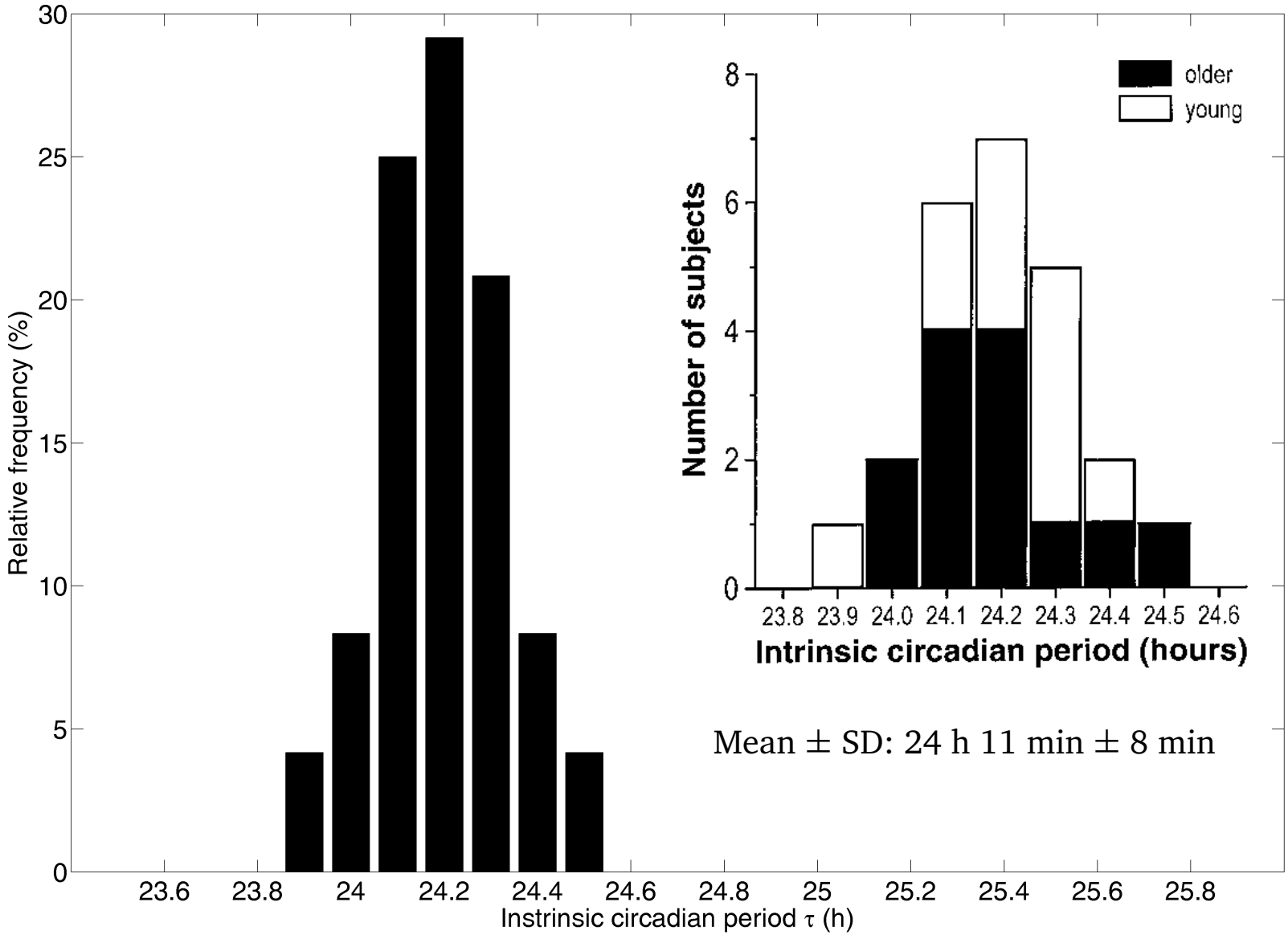
20-hour "day"
6:40 hours of sleep

28-hour "day"
9:20 hours of sleep



cf. [Czeisler et al. 1999]

Forced desynchrony experiments



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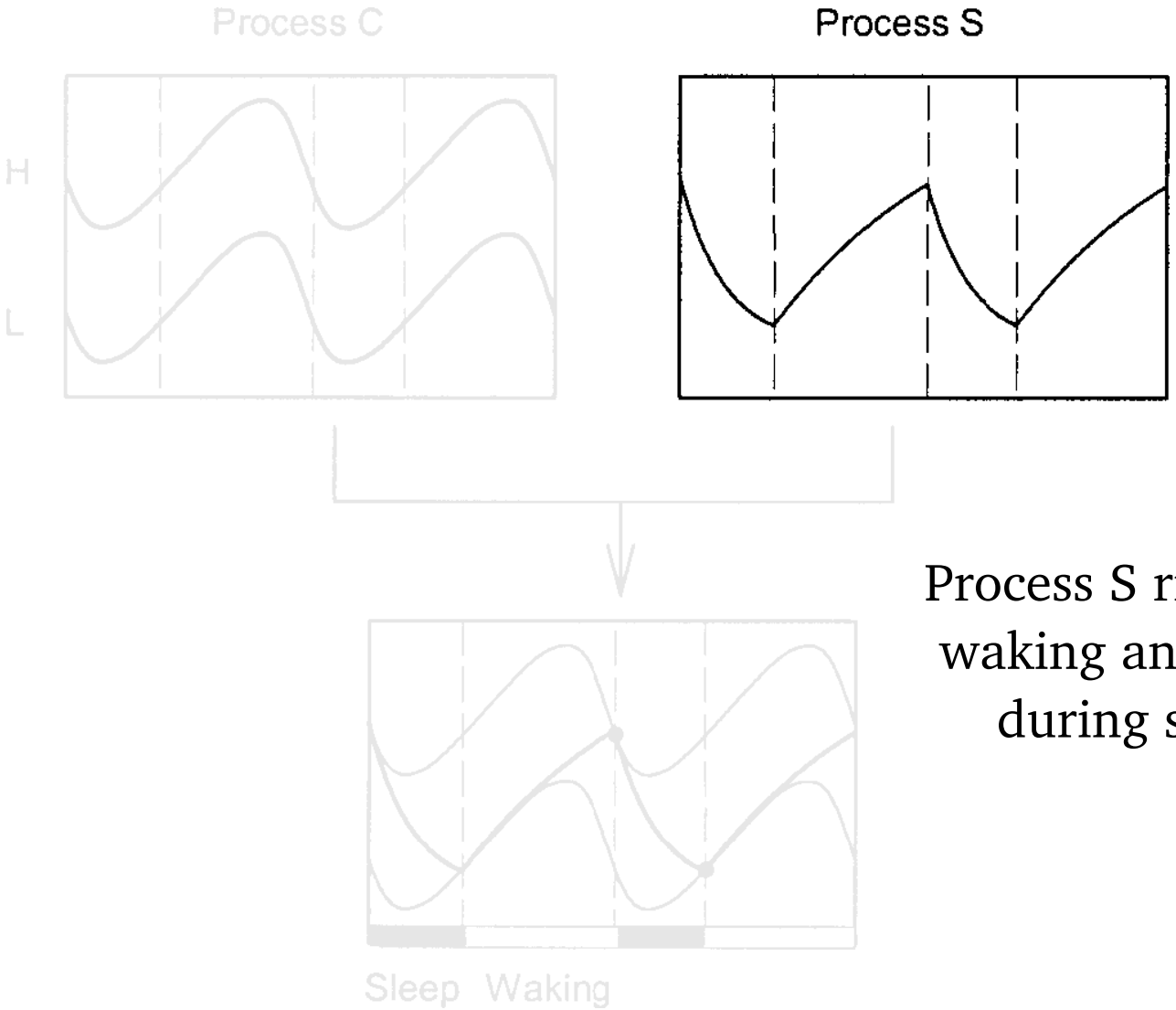
Understand the connection between phenomena

- Which models exist for explaining sleep-wake timing and chronobiological behaviour?
- What relations between different parameters can be revealed by combing existing models?

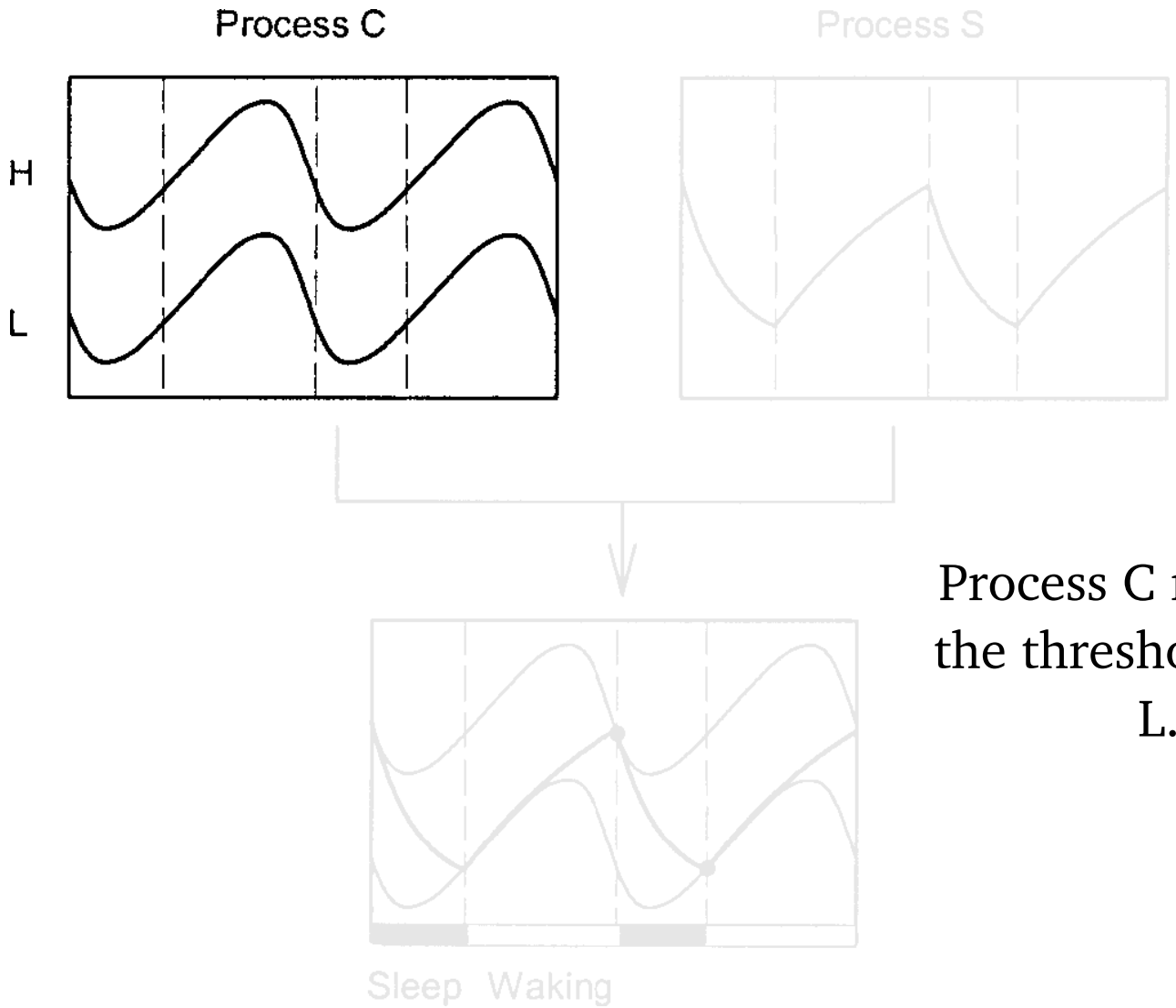
Two-process model



Process S rises during waking and declines during sleep.

cf. [Achermann 2004]

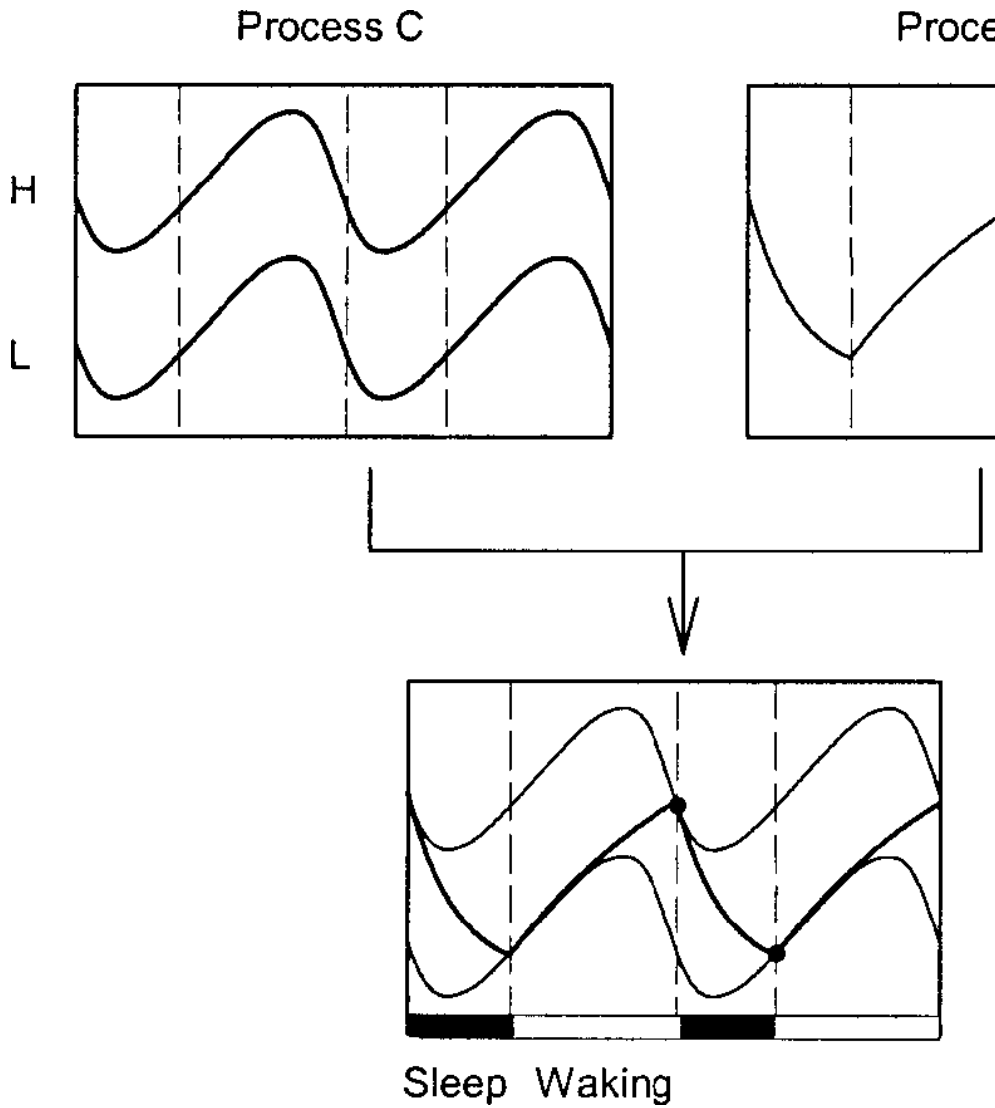
Two-process model



Process C modulates the thresholds H and L.

cf. [Achermann 2004]

Two-process model

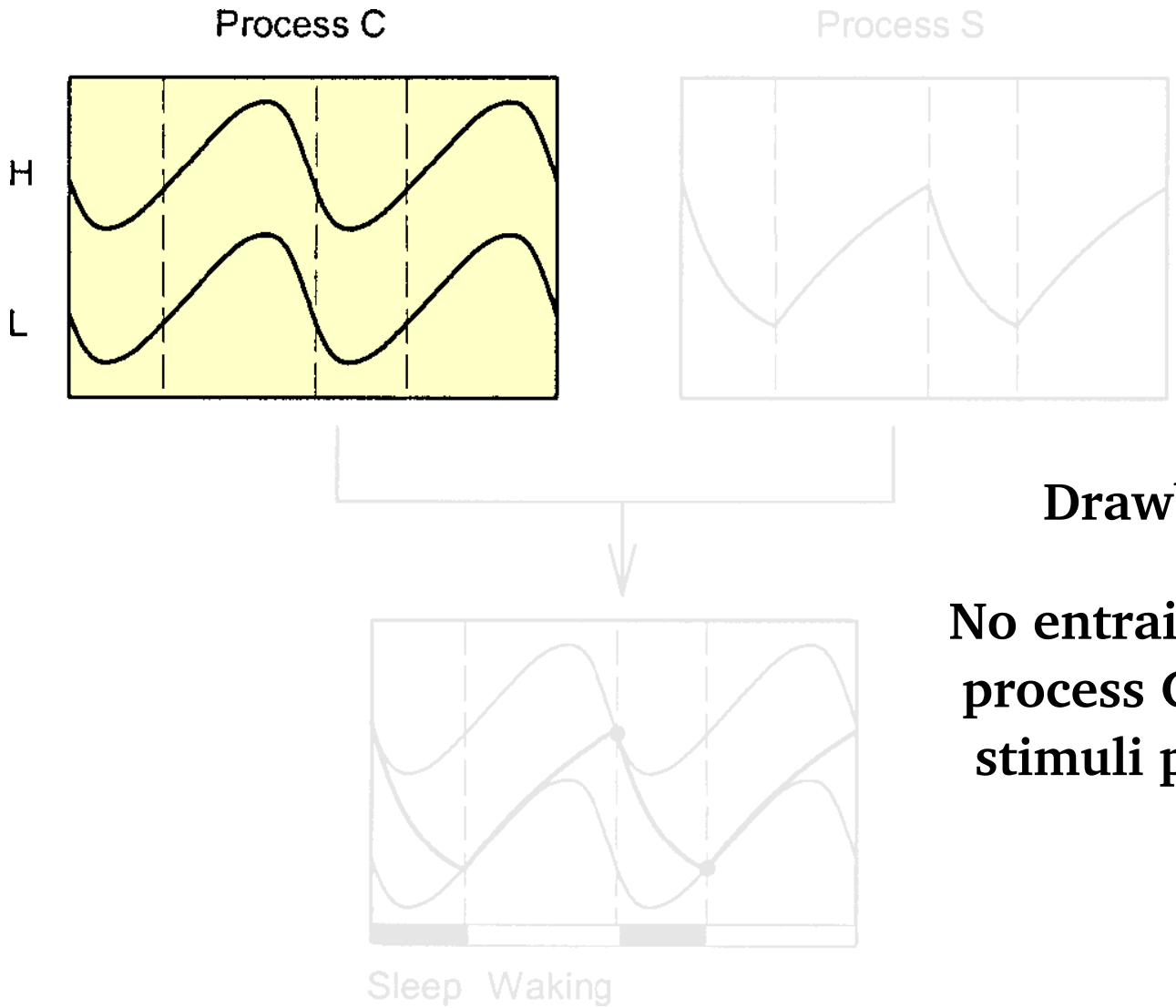


Sleep regulation:

Interaction of S with H and L determines the onset and termination of a sleep episode.

cf. [Achermann 2004]

Two-process model

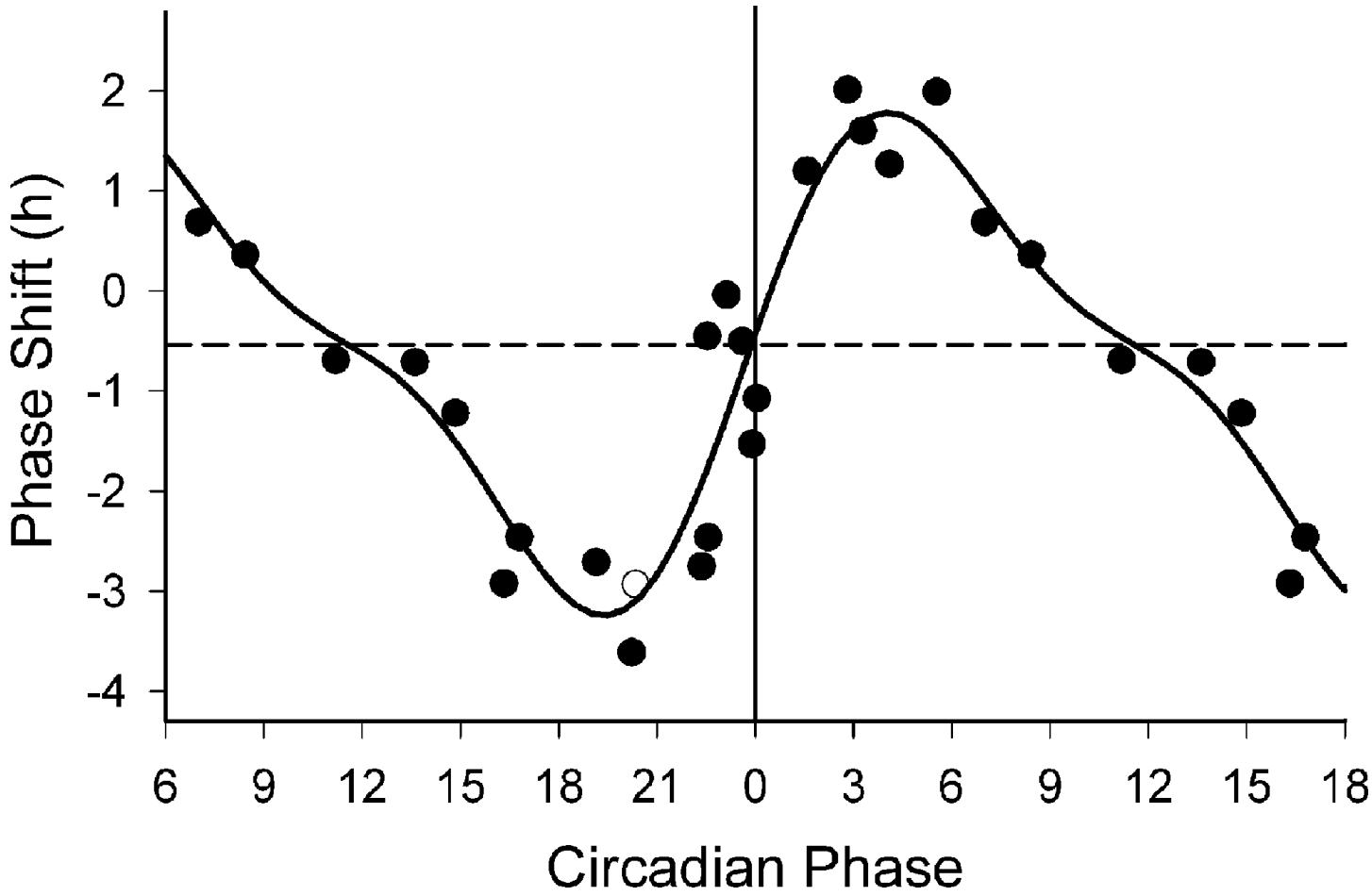


Drawback:

No entrainment of process C to light stimuli possible.

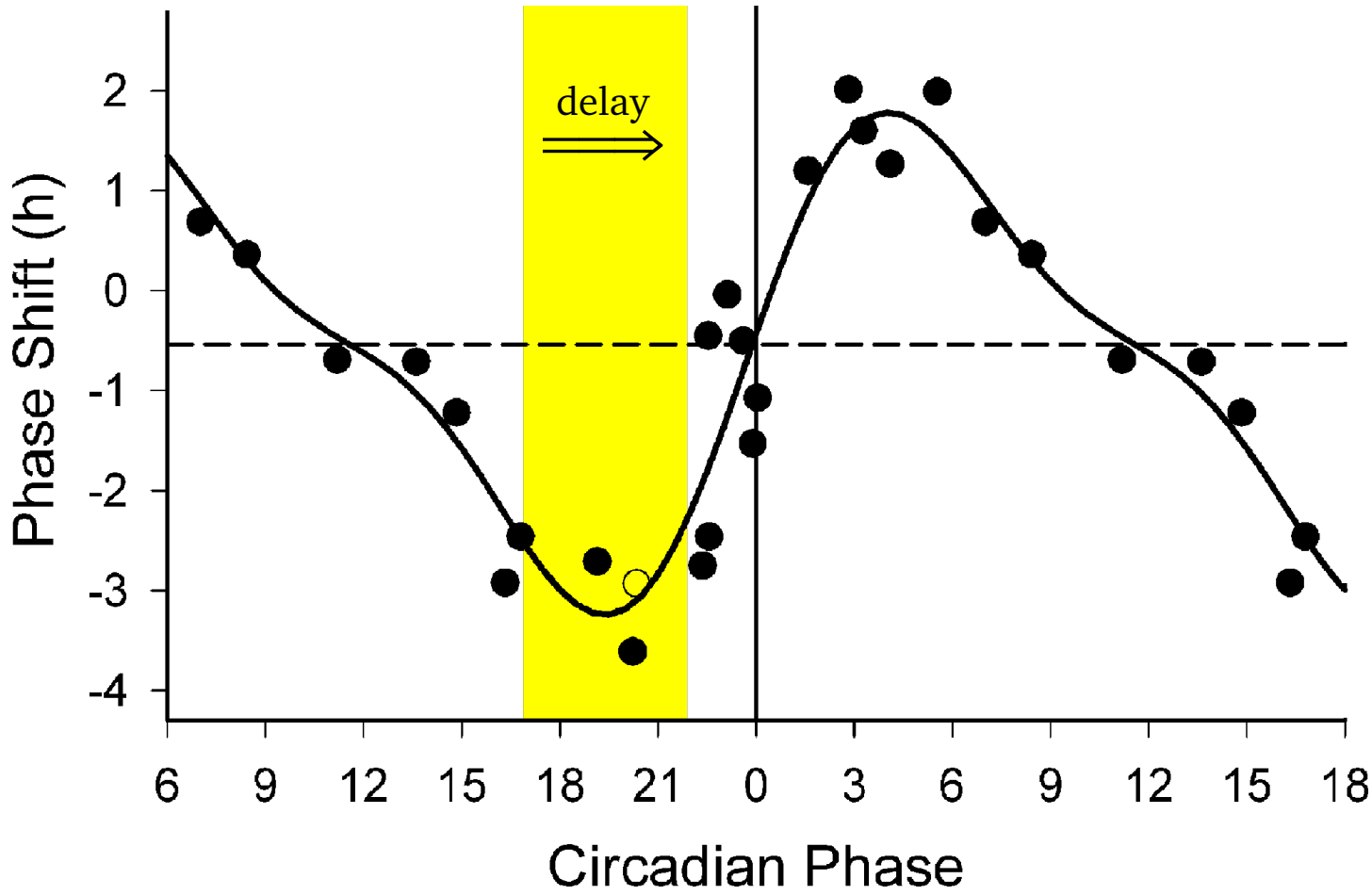
cf. [Achermann 2004]

Phase response curve to light



cf. [Khalsa et al. 2003]

Phase response curve to light



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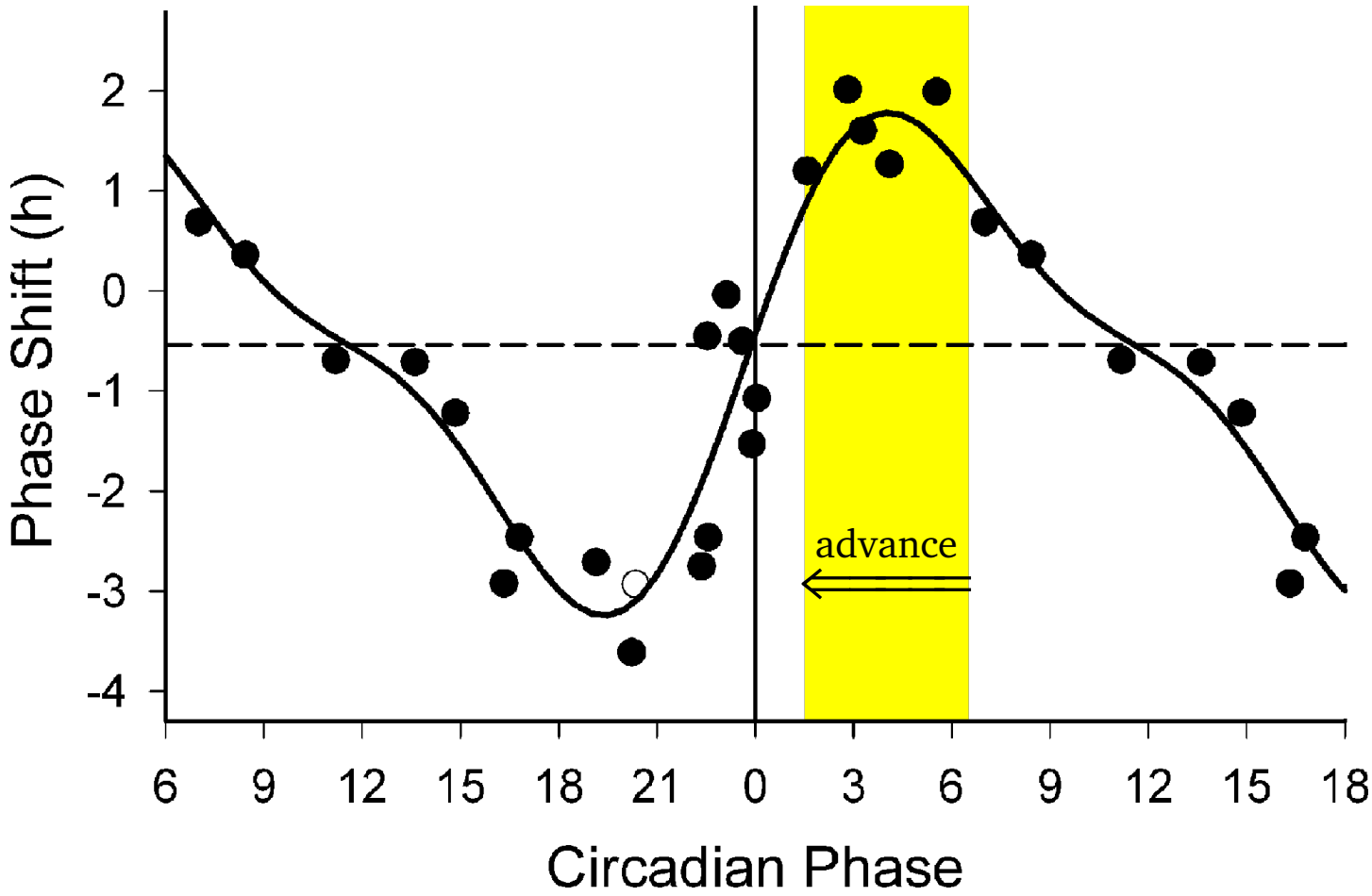
Phase response curve to light



cf. [Khalsa et al. 2003]

Extended Two-Process Model

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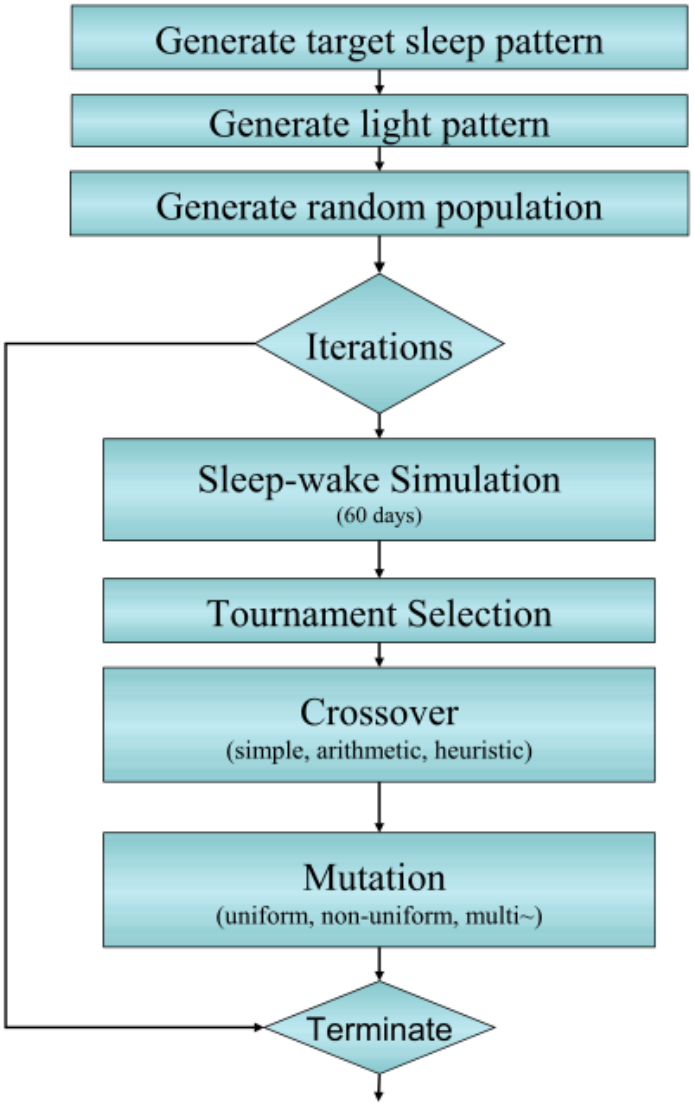
τ, amplitude C_L & C_H, level C_L & C_H, ϕ_C, $\Delta\phi_{\text{C-PRC}}$, amplitude & width PRC & ARC, ...

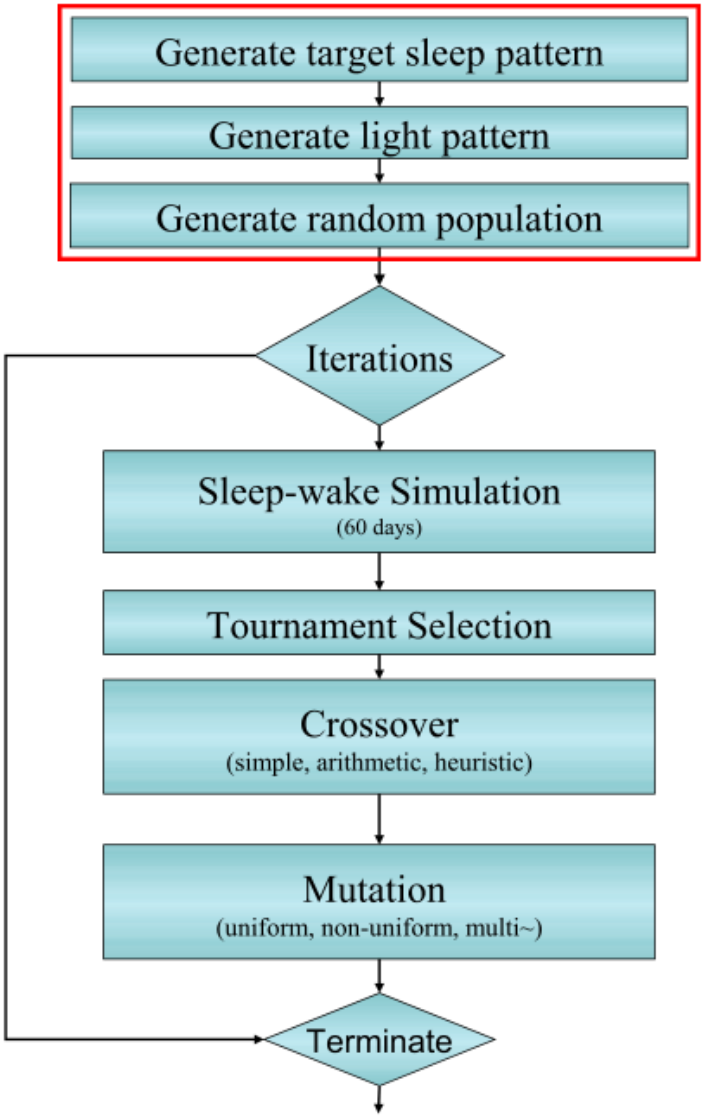
Evolutionary Optimization



Optimize a population of chronotypes:

For each chronotype, model parameters have to be adapted such, that chronotype's sleep-wake behaviour is met with smallest possible error.

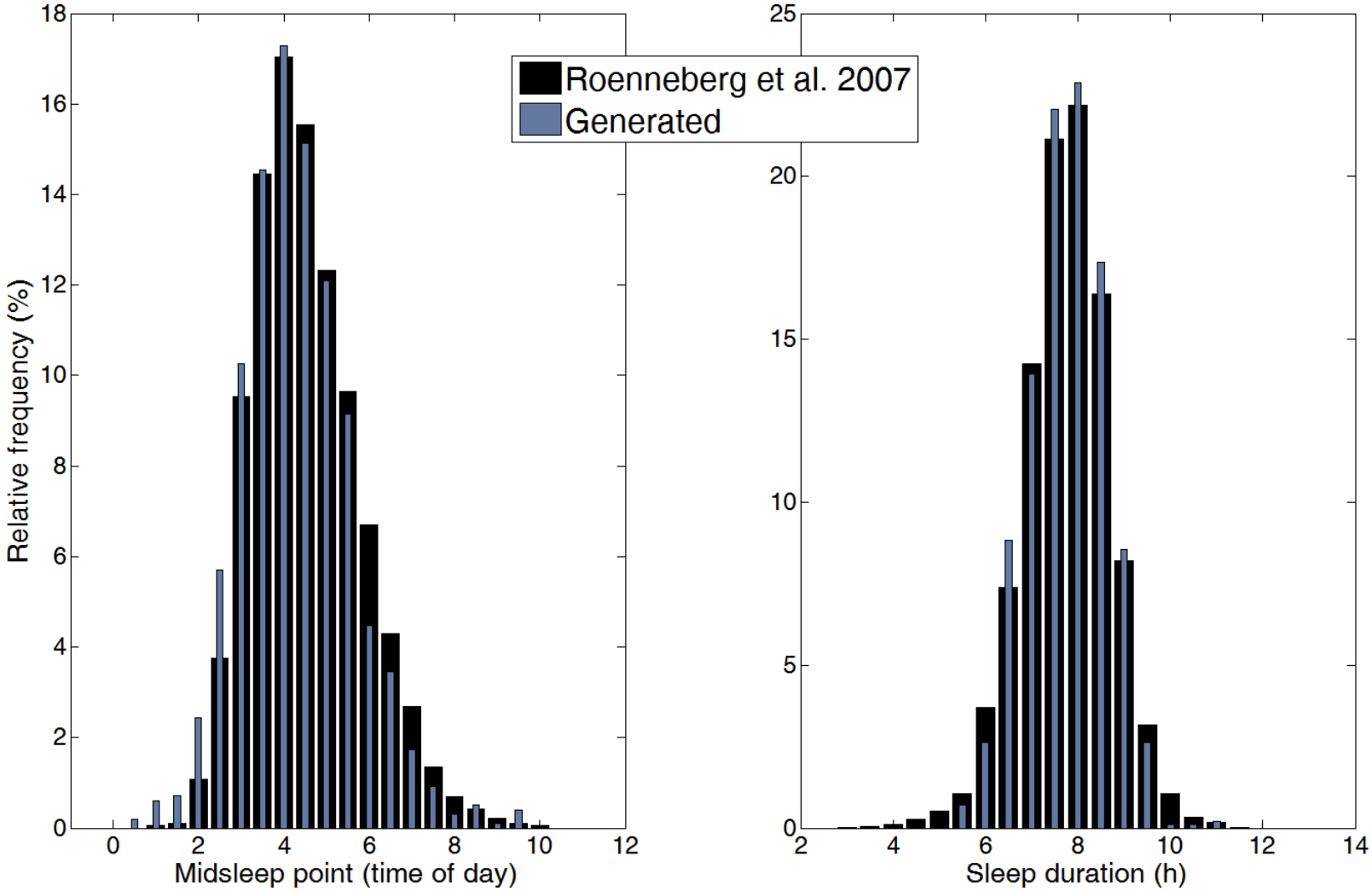
Evolutionary Optimization



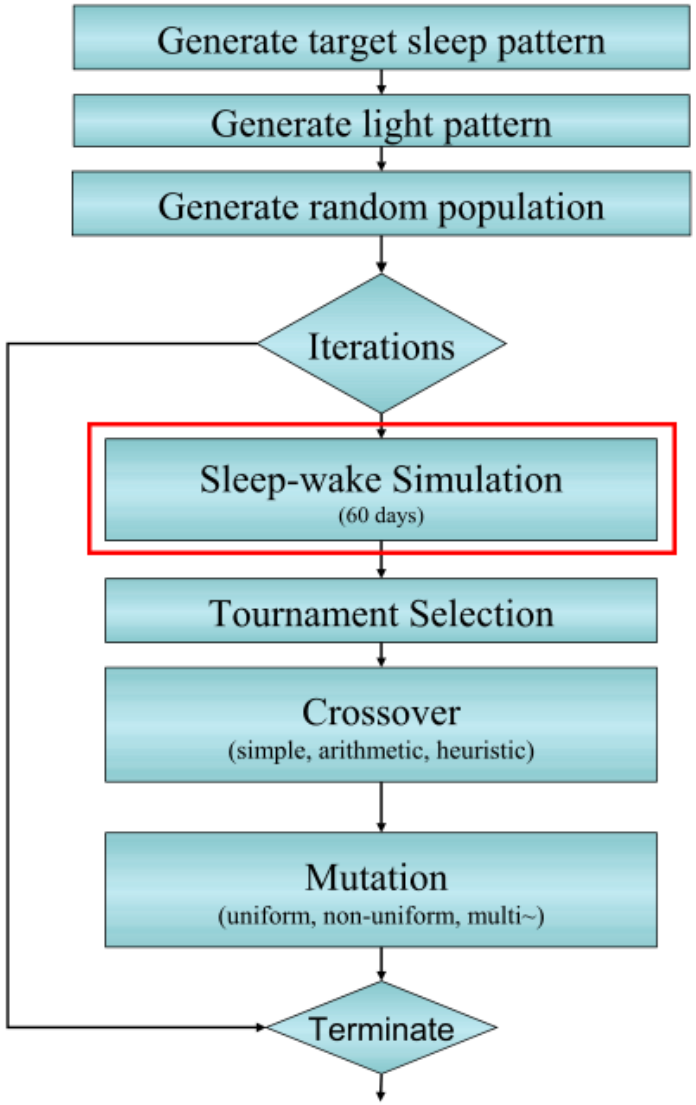
Initialization:

Generate population of chronotypes such, that empirical distribution is met.

Population initialization



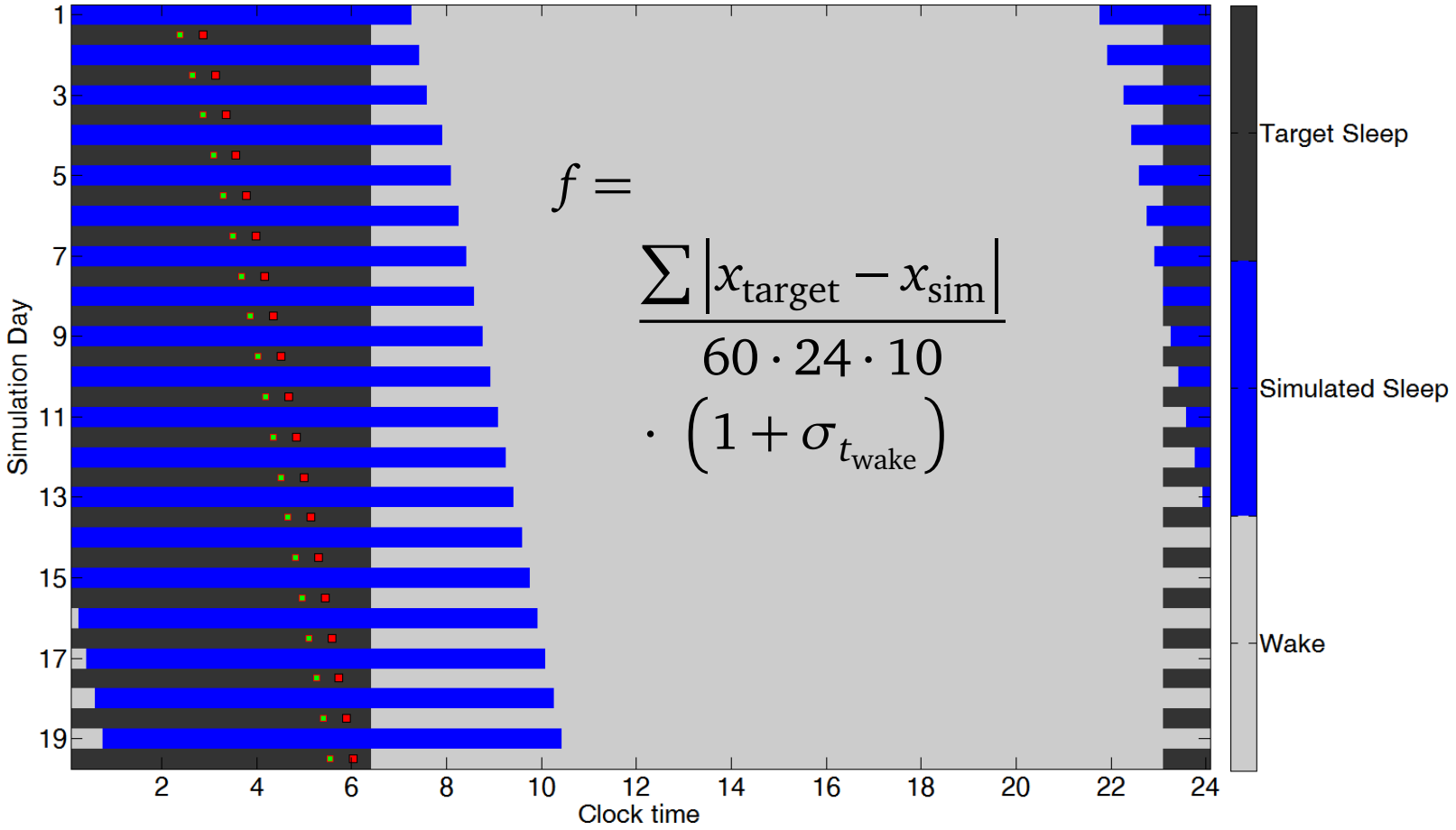
Evolutionary Optimization



Fitness assignment:

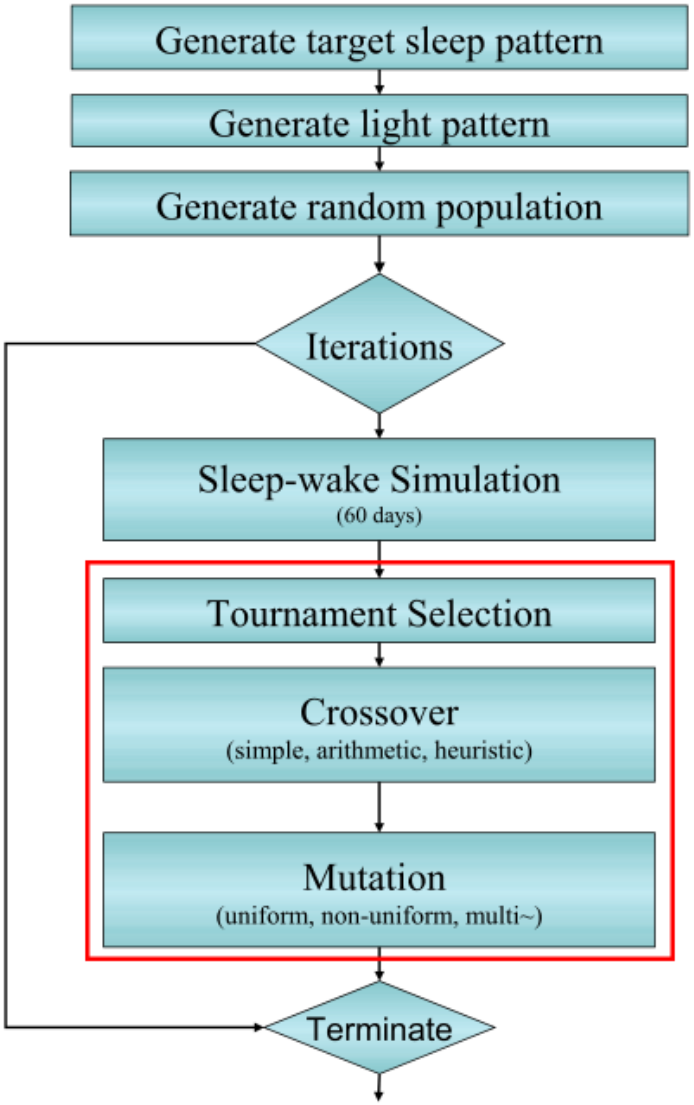
Calculate deviation of simulated sleep-pattern from target sleep-pattern.

Fitness assignment



$$f = \frac{\sum \left| x_{\text{target}} - x_{\text{sim}} \right|}{60 \cdot 24 \cdot 10} \cdot \left(1 + \sigma_{t_{\text{wake}}}\right)$$

Evolutionary Optimization



Various evolutionary operations applied.

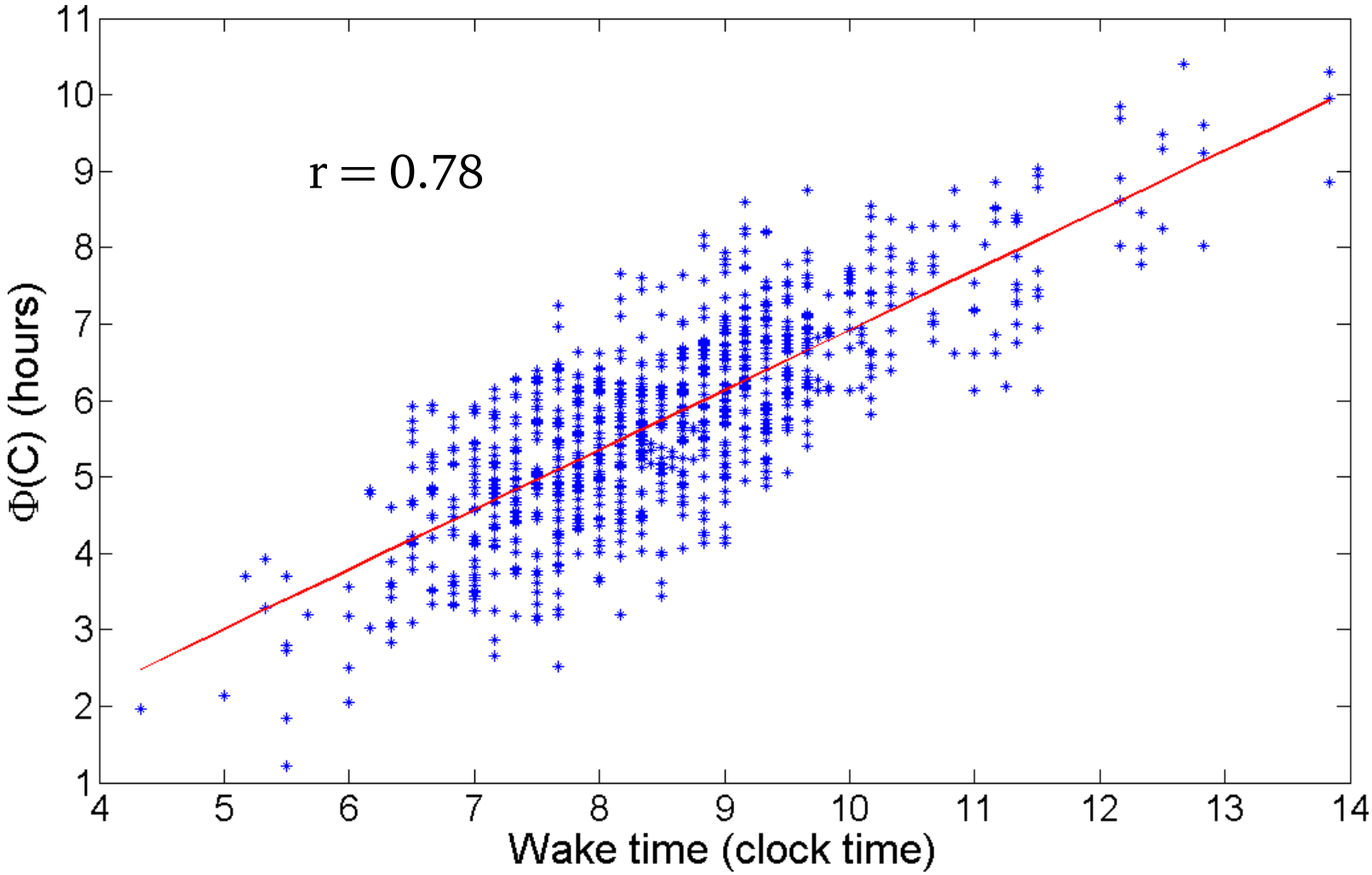
Probability for each ...

crossover variant = 12%

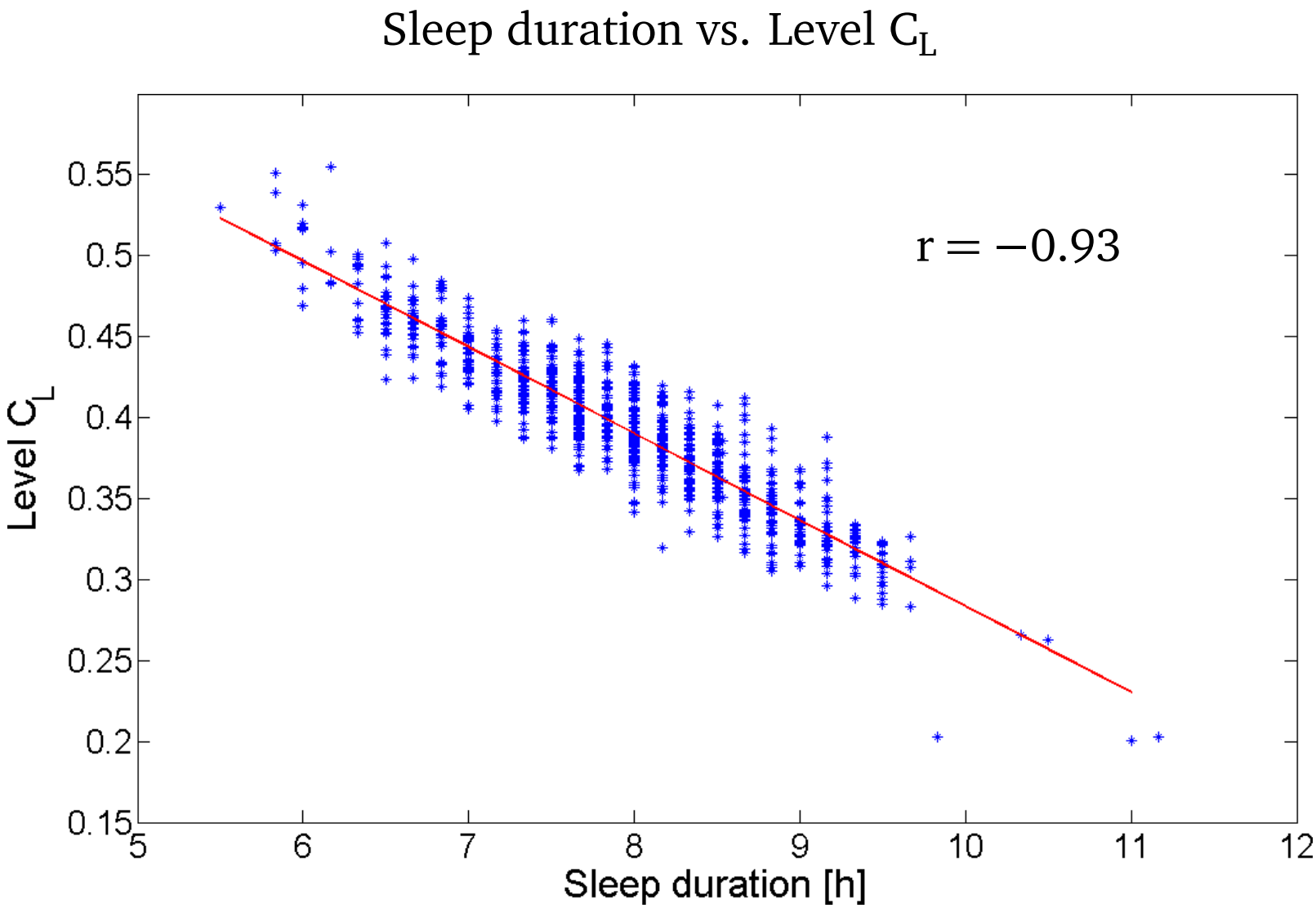
mutation variant = 15%

Model parameter correlations

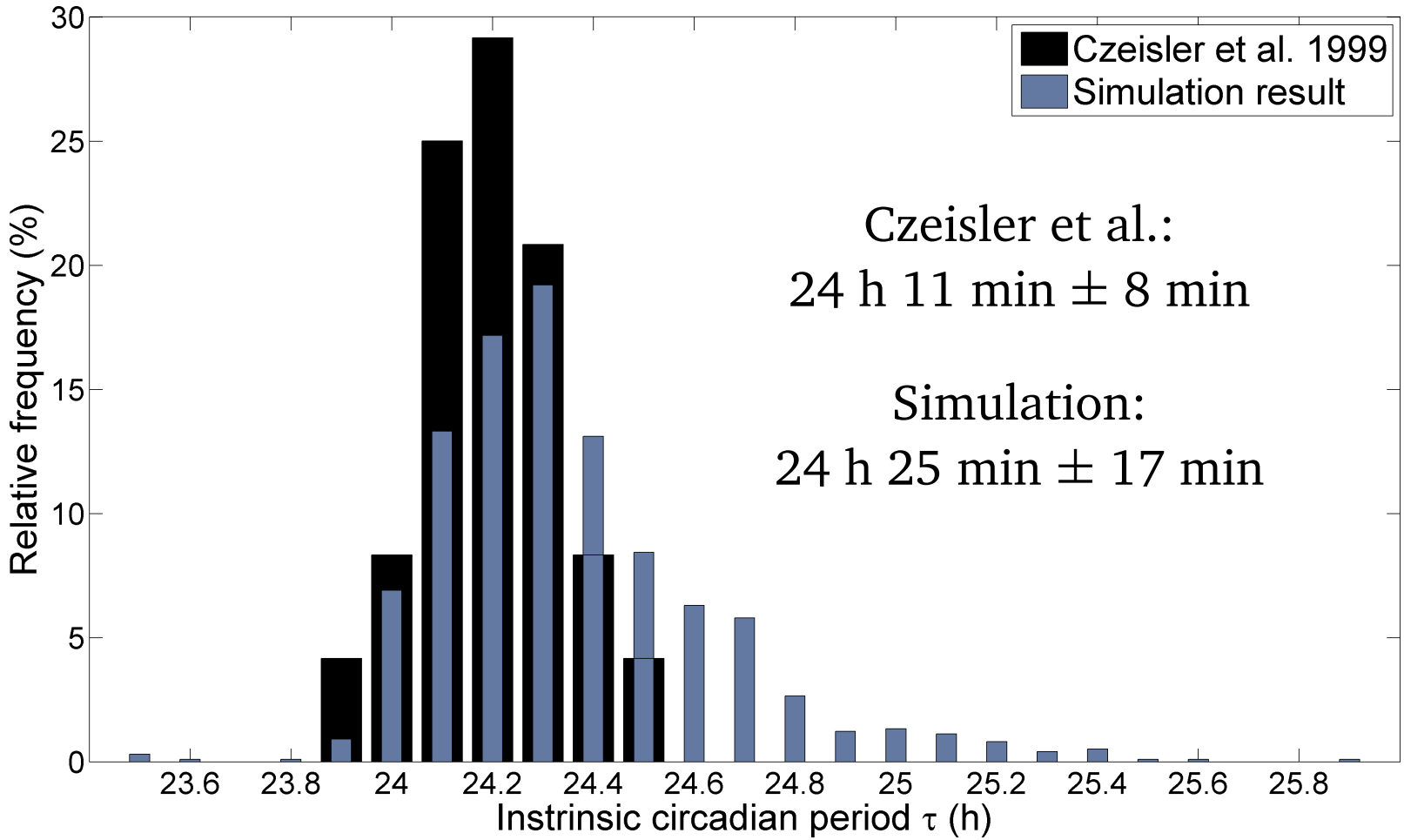
Wake time vs. ϕ_C



Model parameter correlations



Distribution of circadian periods



Conclusion

Model extension

Feedback loop established between sleep-wake behaviour and chronobiological responses.

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Not mastering all light conditions yet

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- Plausible results for day-night equilibrium
- Unrealistic for extreme day/night length differences

Current work

Make subharmonic periodic components of process C available to optimization — good agreement of simulated and empirical sleep episodes in a current study.

Literature references I

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