Dynamics of Sleep-Wake Transitions During Sleep

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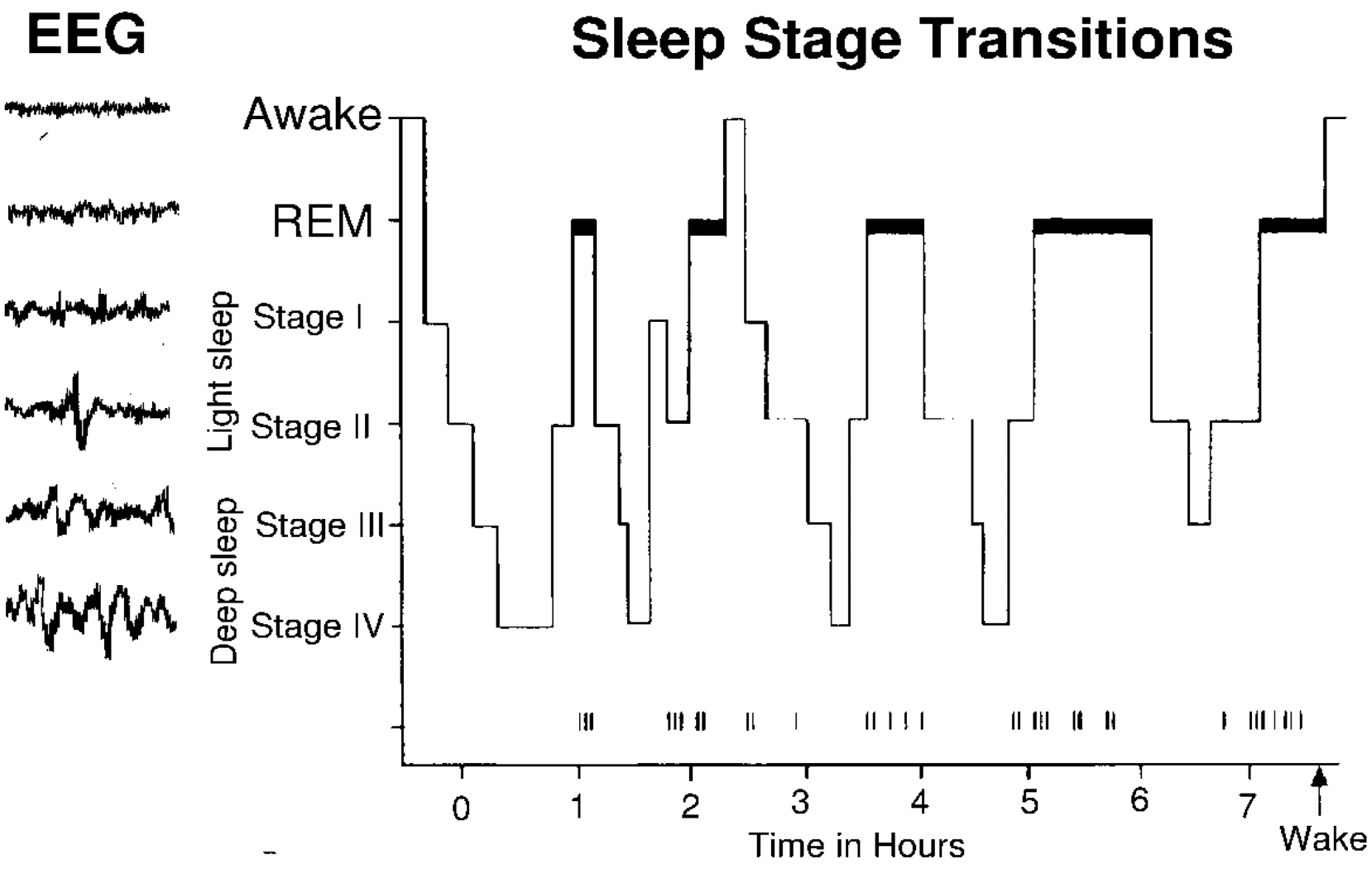
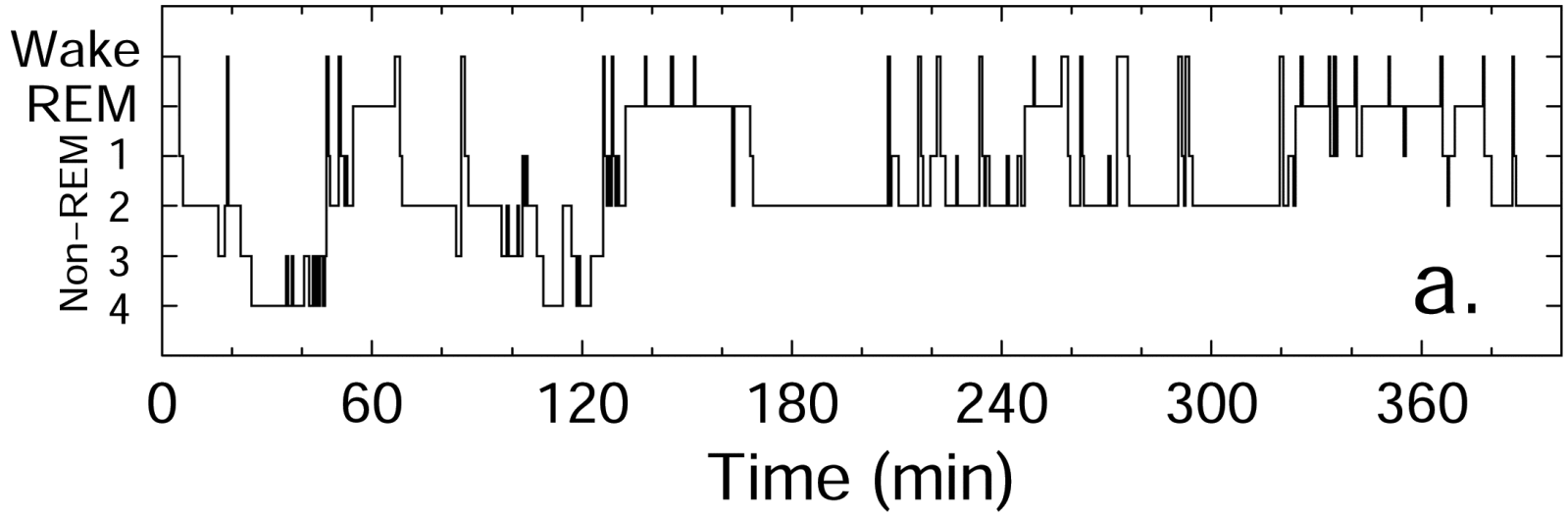
Sleep-Stage Transitions: Traditional View

S. Chokroverty, Sleep Disorders Medicine, 1999

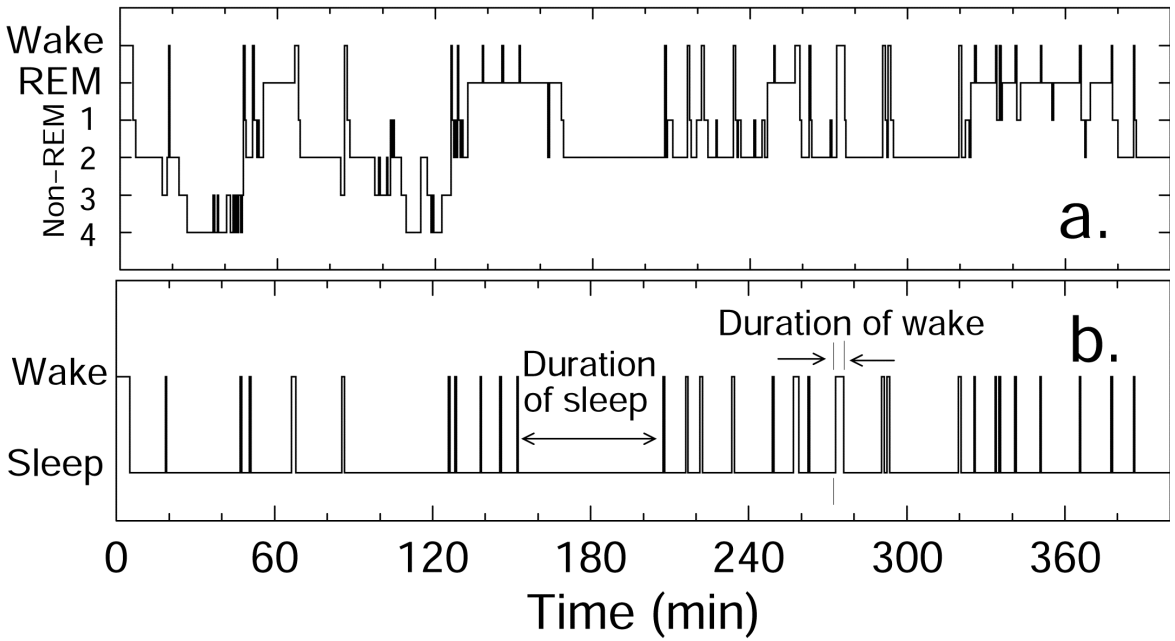


Real Data - What Is the Question?



Real data is more complicated than the textbook picture.

Simplify the Question



Six stages

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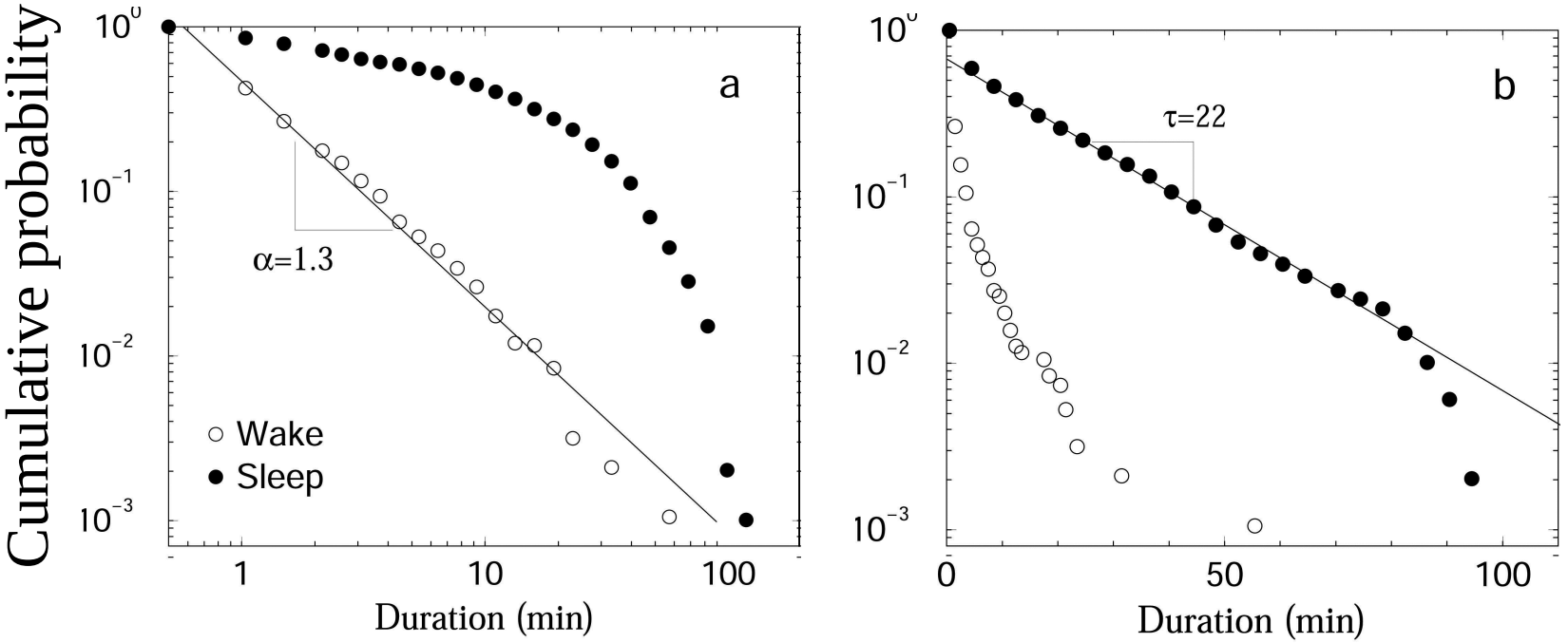
Two states:
sleep and wake

Question:
What are the distributions of sleep and wake duration?

Distributions of duration of sleep and wake periods



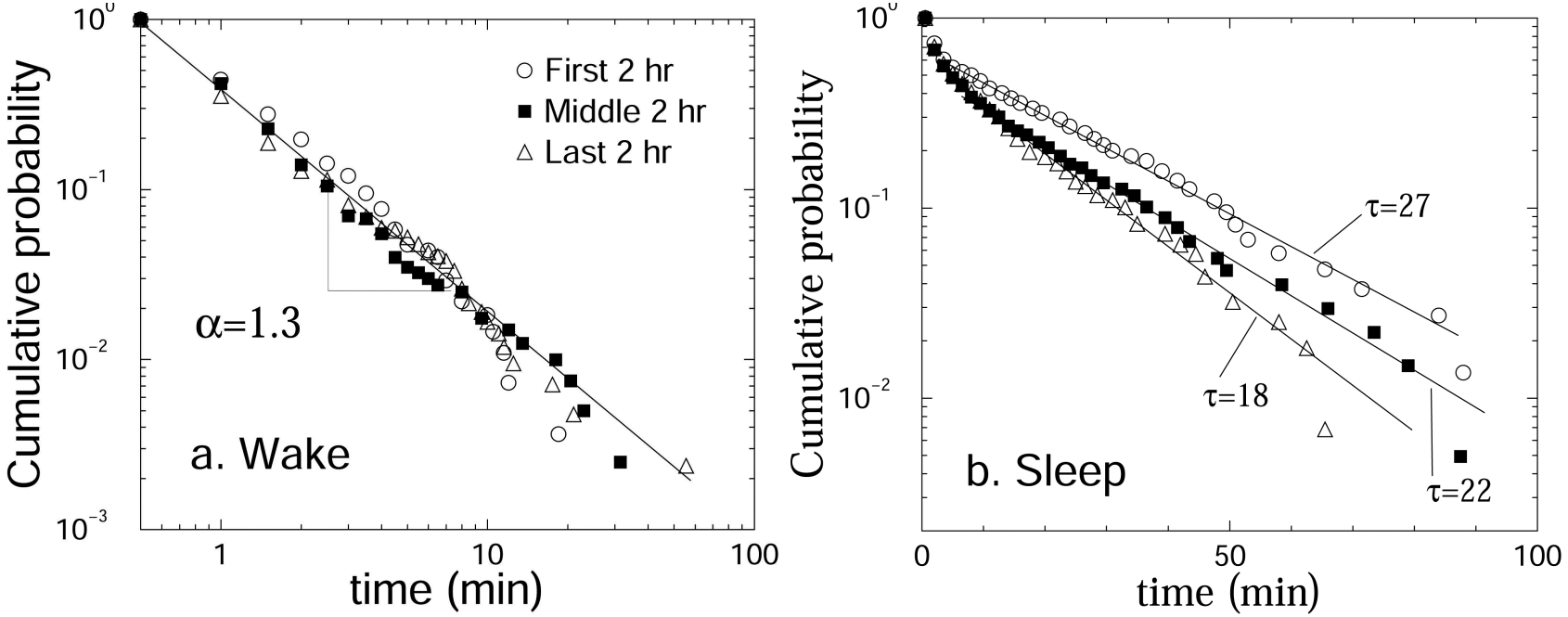
The duration of wake periods follows a power law distribution

$$P(t) \propto t^{-\alpha}$$

The duration of sleep periods follows an exponential distribution

$$P(t) \propto e^{-t/\tau}$$

Stability of distributions of duration



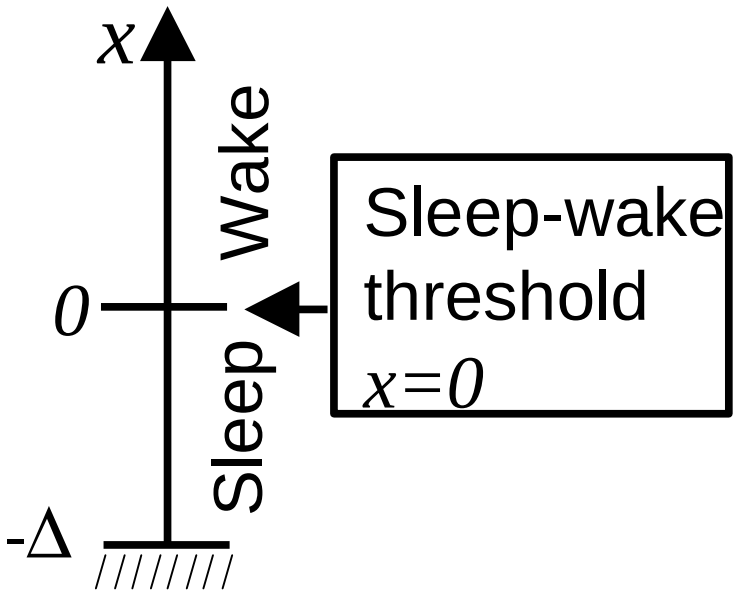
The scale-free behavior of wake duration does not change throughout the night

In contrast, the time scale of sleep duration changes with time.

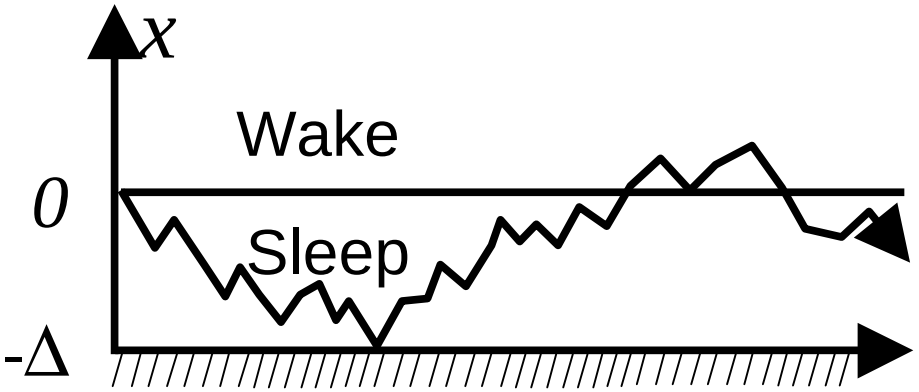
Assumption 1 & 2: Microstates & Dynamics

1. Both wake and sleep macro states comprise large number of microstates.

- Map the state of the system onto a continuous variable: $x(t)$



2. The state x might be presented by a random-walk type of dynamics.



Assumption 3: Restoring force

3. In order to maintain sleep, there are supposed be a "restoring force" pulling the system towards the sleep state when the system moves into wake state.

The restoring force is very strong near the threshold and becomes weaker as one moves away from the threshold

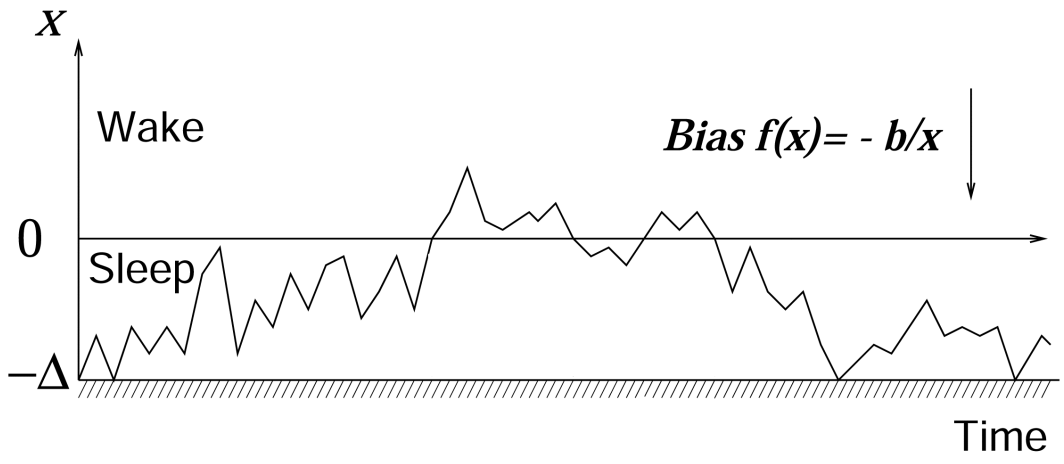
$$f(x) = -b / x$$

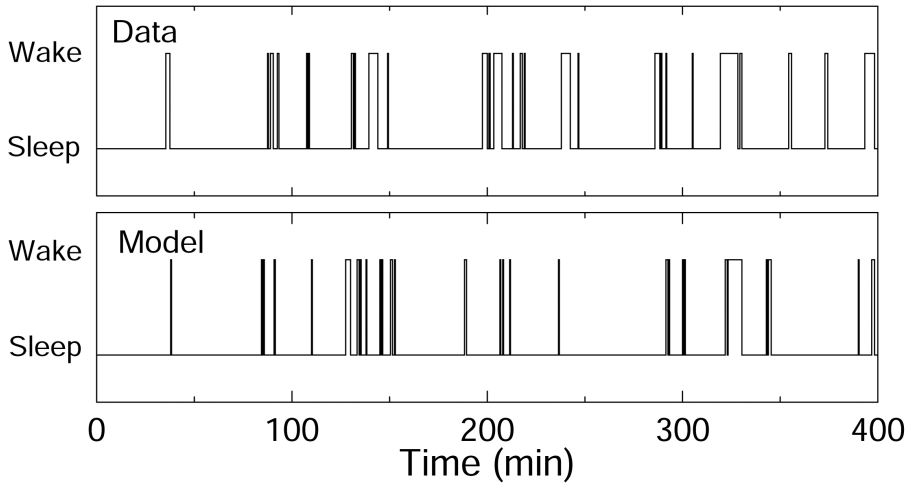
A Stochastic Model

The model can be written as:

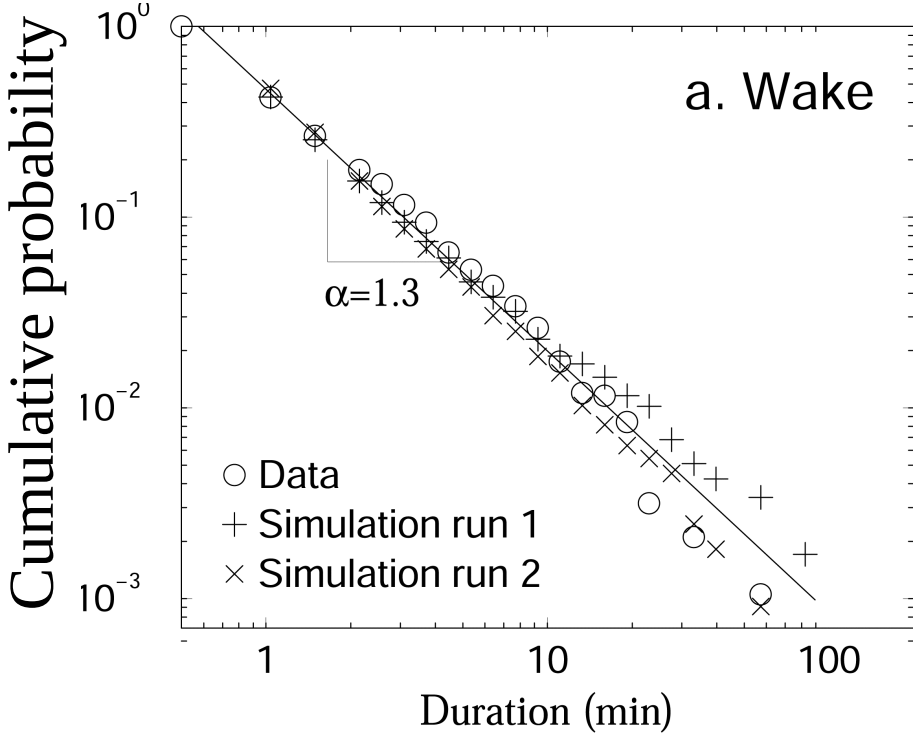
$$\delta x(t) \equiv x(t+1) - x(t) = \begin{cases} \epsilon(t), & \text{if } -\Delta \le x(t) \le 0 \quad \text{(sleep)}, \\ -\frac{b}{x} + \epsilon(t), & \text{if } x(t) > 0 \quad \text{(wake)}, \end{cases}$$

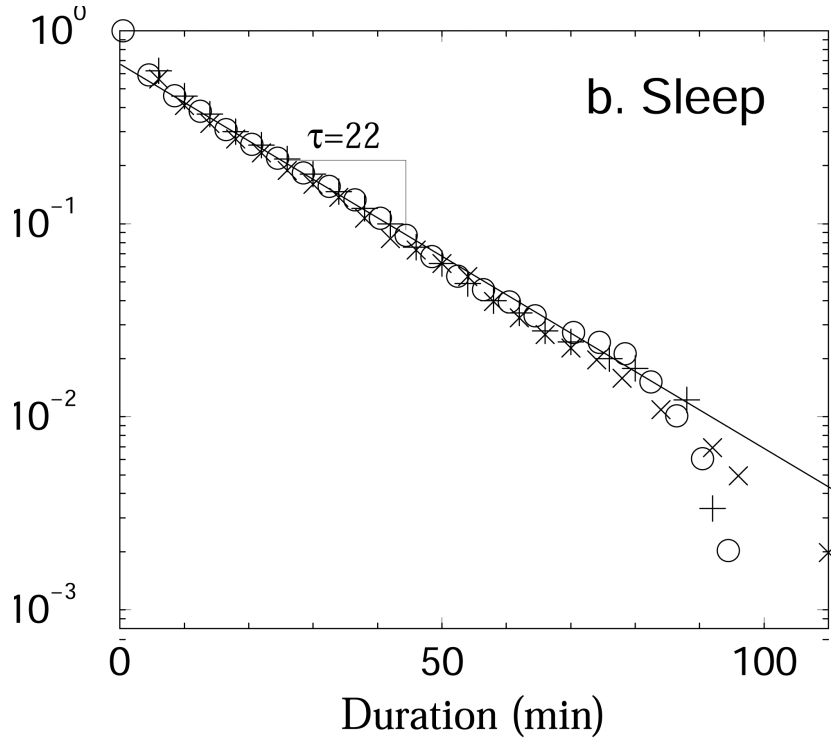
The model has two parameters: b & Δ





The Results of the simulations





The power-low exponent of the wake duration in the model is given by:

$$\alpha = 1/2 + b$$

The characteristic time of the sleep is given by:

$$\tau \sim \Delta^2$$

Summary

- The sleep-control mechanism accommodates two completely different types of dynamics:

Sleep → exponential distribution (variant)
Wake → power-law distribution (invariant)

- The empirical results can be modeled by a biased random walk.

- The difference in the distribution between the wake and sleep arises from the constraints on the number of microstates.

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