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Signal recording and non-linear signal processing for interacting signals in sleep research

CHARITÉ
UNIVERSITÄTSMEDIZIN BERLIN

Thomas Penzel

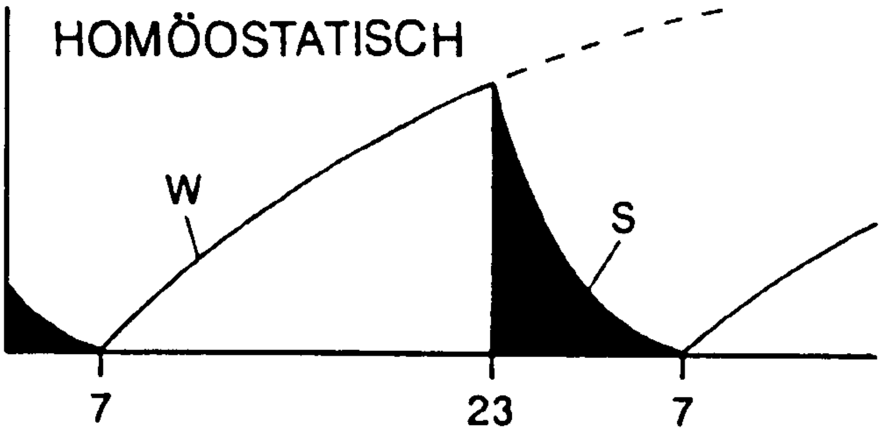
Sleep Medicine Center, Berlin, Germany

Why do we sleep?

Functions of sleep:

- Physical restoration
- Mental restoration
- Memory functions
- Hormone secretion
- Immune system
- Performance restoration
- Synaptic homeostasis

Regulation of sleep:



Sleep disorders: complaints and symptoms

Insomnia:
- Disorders of initiating and maintaining sleep (DIMS) (e.g. stress, light, noise, coffee, or pain)

Hypersomnia:
- Excessive daytime sleepiness (DOES)
- Unintended falling asleep during monotonous tasks (e.g. too short sleep, or sleep apnea, narcolepsy)

Parasomnia:
- Disorders occuring during sleep (Bruxism=tooth grinding, sleep walking, frightening dreams)

International Classification of Sleep disorders

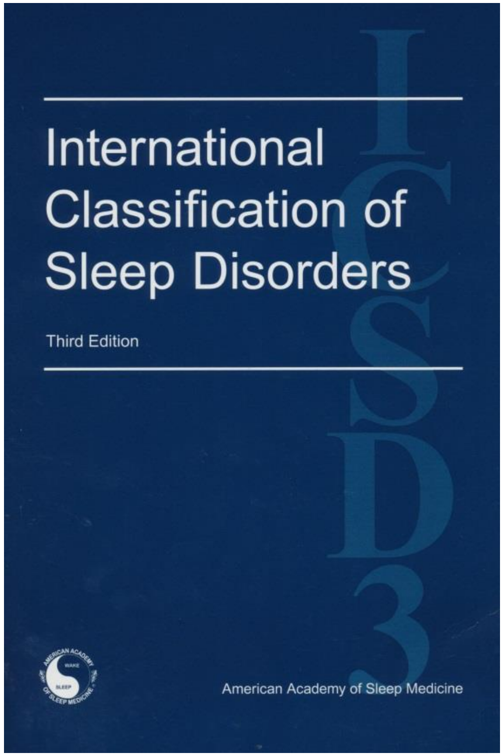
Main categories of ICSD-3

1. Insomnia
2. Sleep related breathing disorders
3. Central disorders of hypersomnolence
4. Circadian rhythm sleep wake disorders
5. Parasomnias
6. Sleep related movement disorders
   (a total of 67 definitions)
   other sleep disoders

Appendix:

A Sleep related medical and neurological disorders

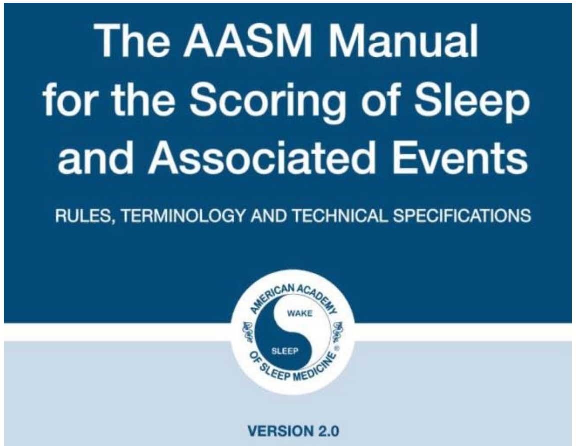
B Substance induced Sleep disorders



Am. Acad. Sleep Med. ICSD-3, 2014

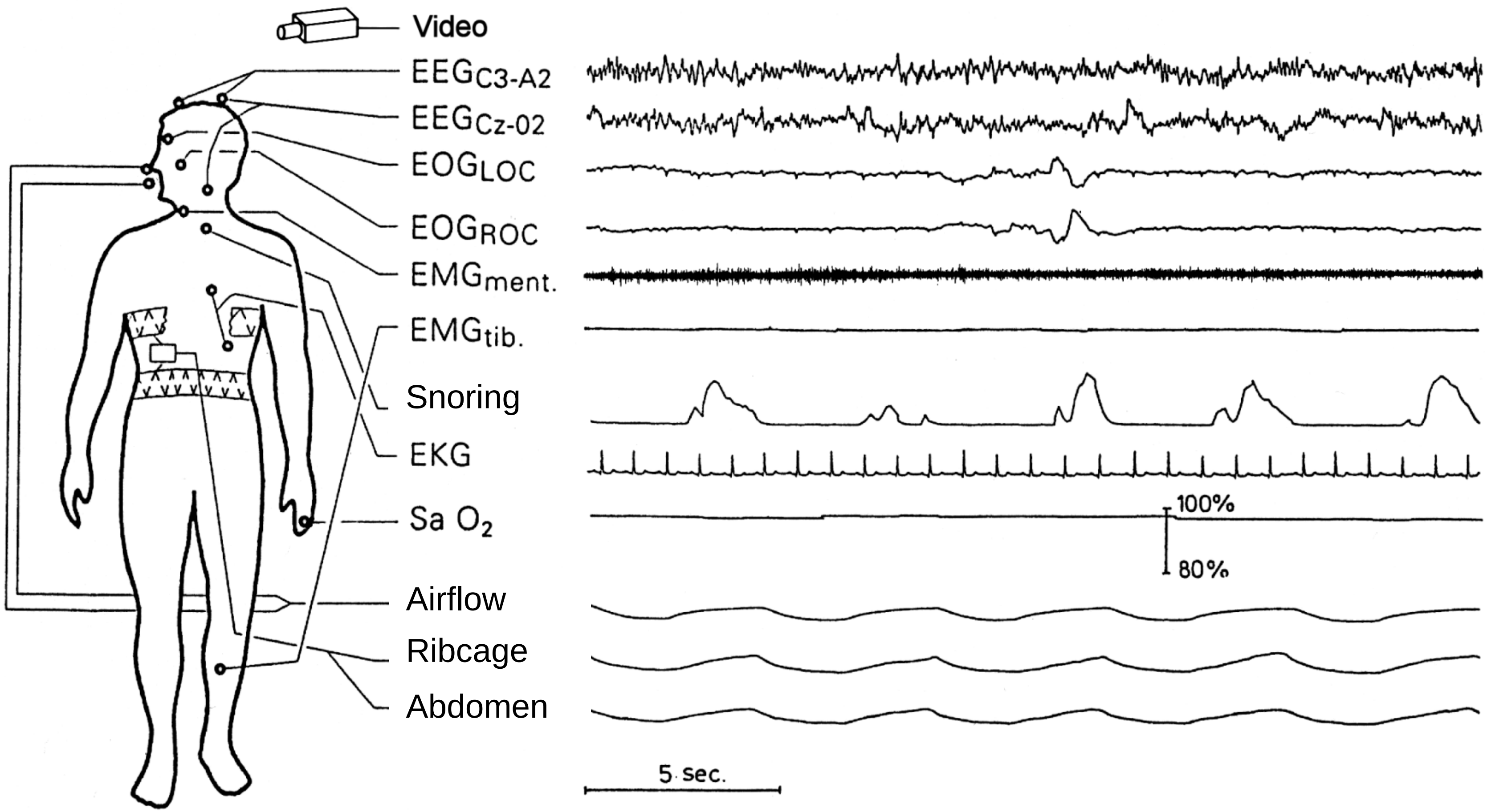
Cardiorespiratory polysomnography - AASM 2.4

- Parameters to be reported
- Technical and digital specifications
- Visual rules (for adults and children)
- Arousal rule
- Cardiac rules
- Movement rules
- Respiratory rules (for adults and children)
- Home sleep apnea testing
- Development process / procedural notes



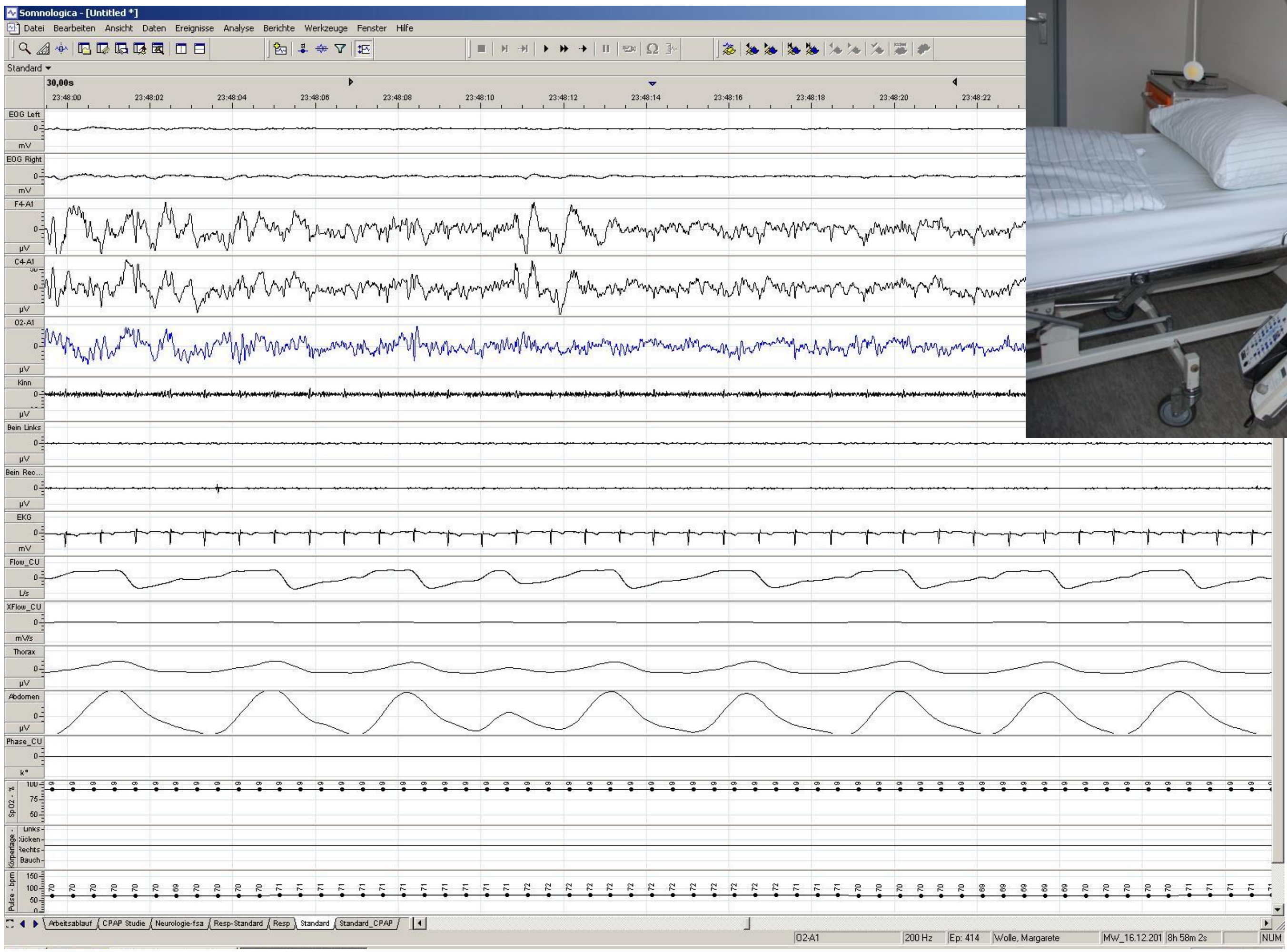
Berry RB, Brooks R, Gamaldo CE, Harding SM, Marcus CL, Vaughn BV for the American Academy of Sleep Medicine. The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, 2st ed.: Darien, Illinois: American Academy of Sleep Medicine, (2017).

Cardiorespiratory Polysomnography



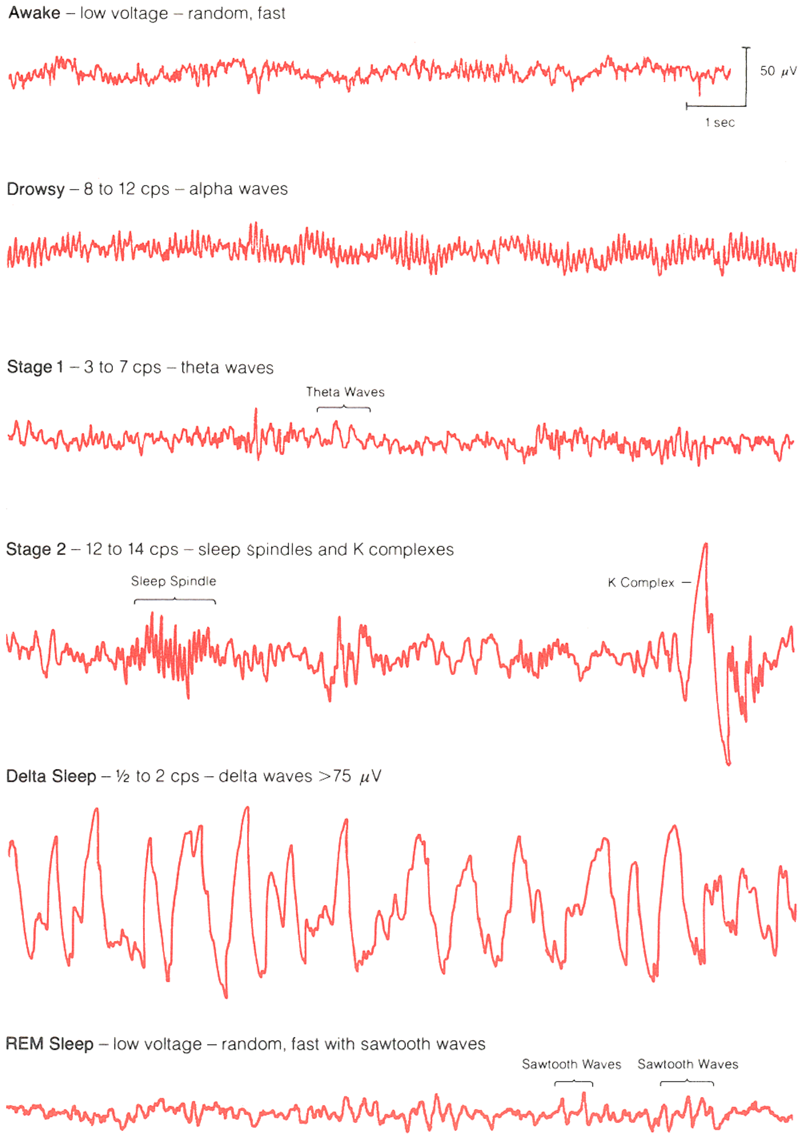
Sleep, respiration, cardiovascular signals, video monitoring

Cardiorespiratory Polysomnography

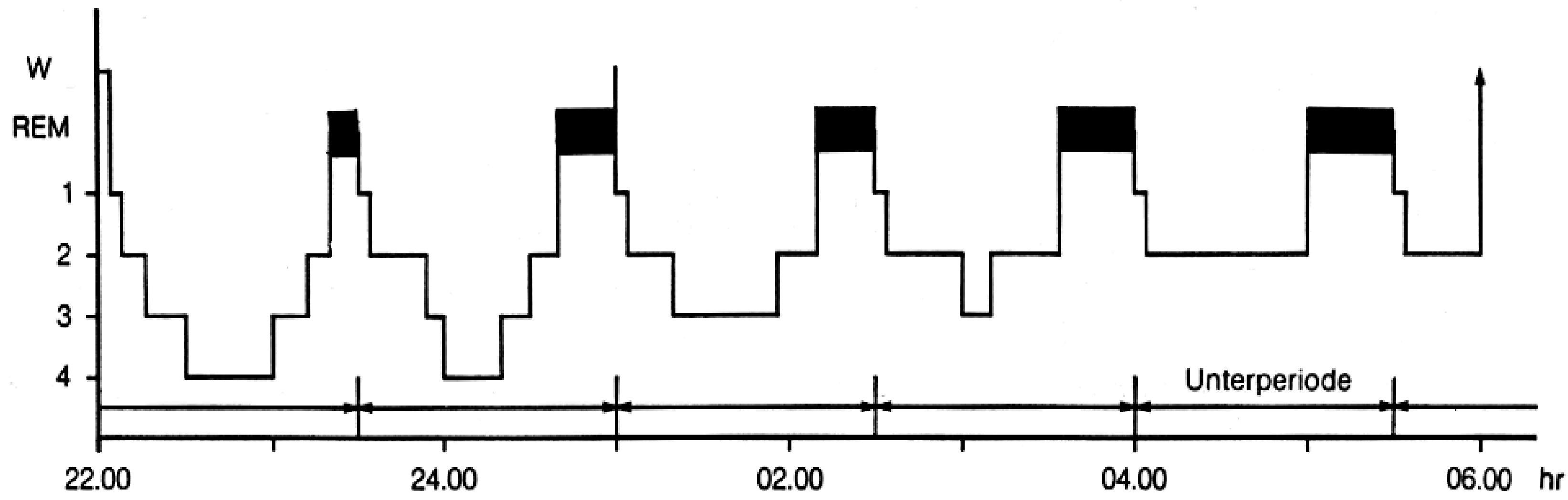


Sleep, respiration, cardiovascular signals, video monitoring, snoring

Sleep EEG – characteristic patterns



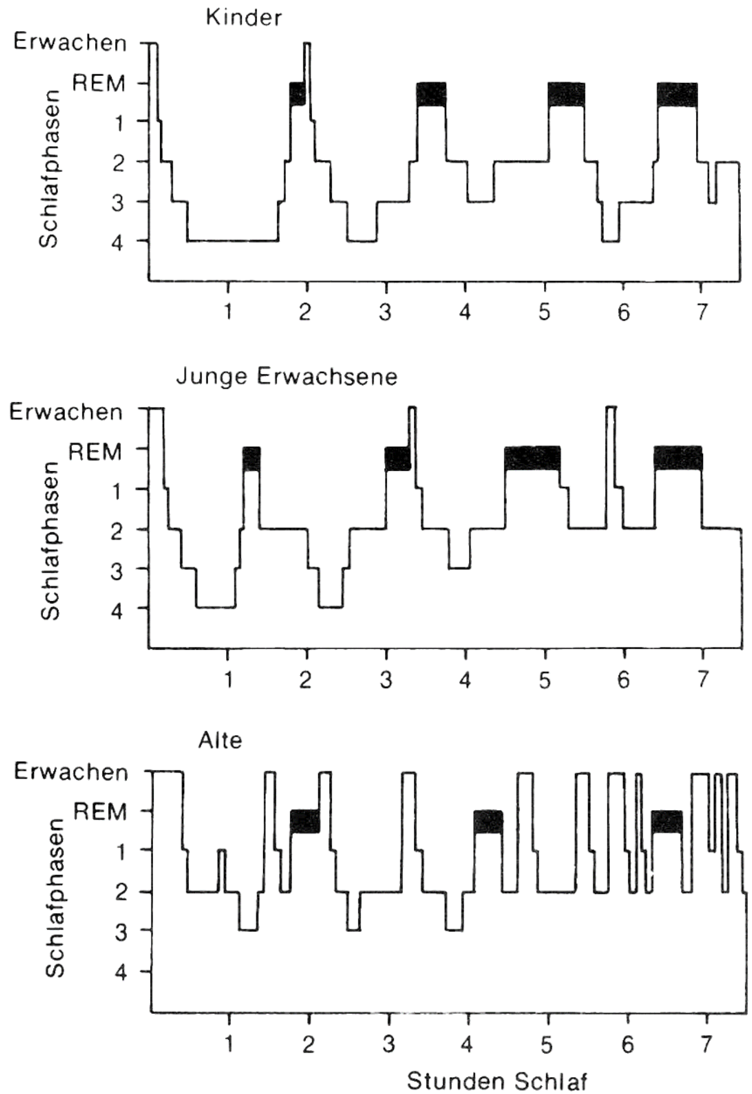
Sleep stage sequence as ideal plot



Current evaluation is statistics:

- Duration and percentages for Sleep stage over the night: TIB, TST, %NREM1 etc.
- Sleep efficacy: TST/TIB
- Latencies
- Transitions between sleep and wakefulness

Sleep and age

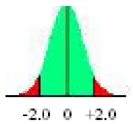


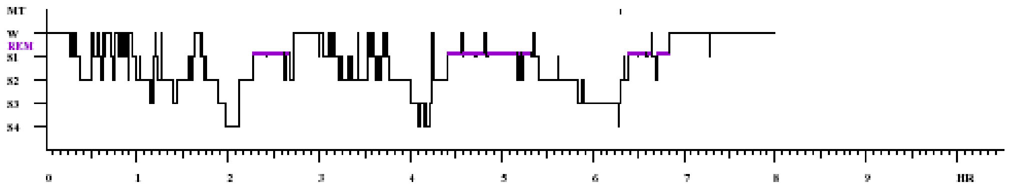
PSG report and comparison with reference data

Patient's ID:	b002702
Patient's gender:	female
Patient's age:	41 years
First Night	No
Recording date:	14.10.1998
Lights out:	23:26:11
End of recording:	07:26:11
Epoch length:	30 s
Number of epochs:	960

Controls: SIESTA normative database
Number of controls: 31 females
Controls' age: 40.2 ± 6 years

z-statistics:
z = (x[Patient] – mean[Controls]) / standard deviation[Controls]
|z| > 1.64 for 10% of controls
|z| > 1.96 for 5% of controls
|z| > 2.58 for 1% of controls
Normal values: green; abnormal values: red





	Patient	mean	z
Time in bed (min)	478.5	477.4	0
Total sleep period (min)	421.5	458.2	-1.3
Total sleep time (min)	345	425	-2.6
Wake within TSP (min)	76	24.4	1.7
Wake after final awakening	42	1.6	3.2
Frequency of awakenings	33	15.5	2.1
Awakening-index (/HR sleep)	5.7	2.2	2.7
Frequency of stage shifts	155	138.1	0.6
Stage shift-index (/HR sleep)	27	19.3	1.5

Latencies (min)	Patient	mean	z
Lights out to S1	15	11.8	0.2
Lights out to S2	21.5	18	0.3
Lights out to S3	67	37.6	1
Lights out to S4	118	45.2	2.4
Lights out to REM	136	101.3	1
Lights out to sleep onset	19	13.1	0.4
LO to 10 min cont. sleep	20	21.2	-0.1
Sleep onset to SWS	48	21.2	1.4
Sleep onset to REM	117	85.6	1

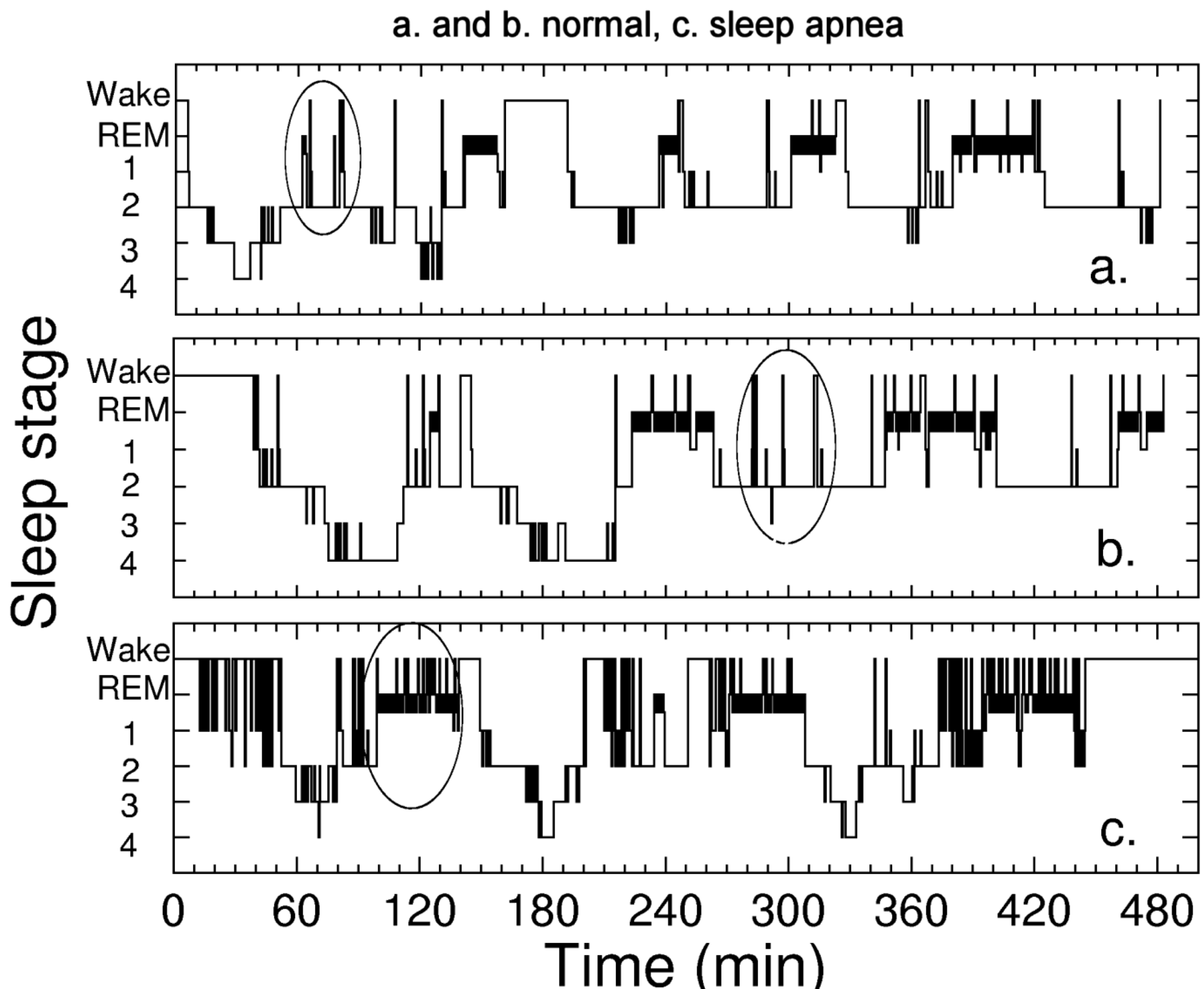
	Patient	mean	z
Sleep efficiency (%TIB)	72.1	90.3	-2.2

Patient: 72.1 %

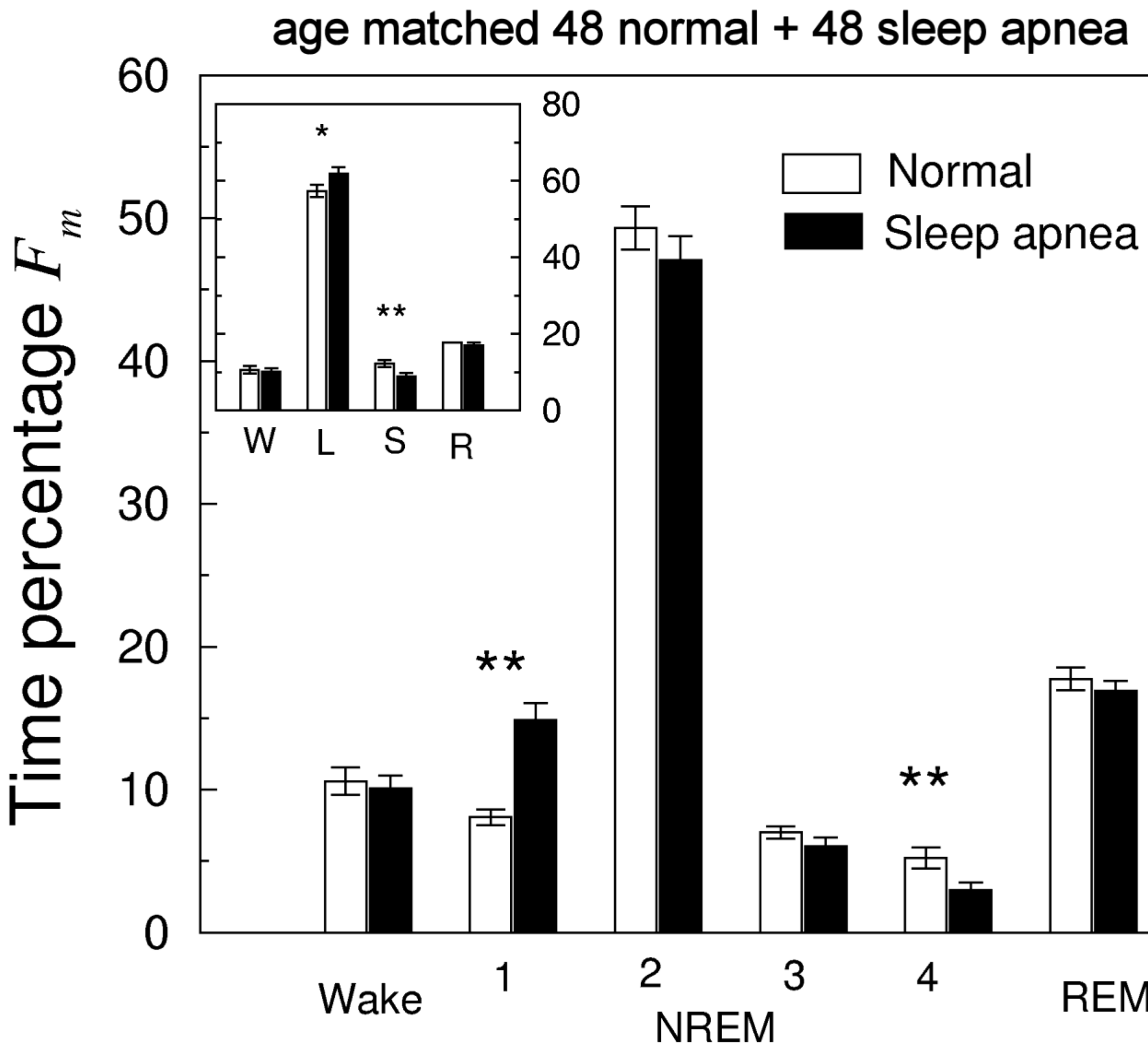
Range for normative values: 75% 97%

Sleep stages	Patient	mean	z
S1 (min)	56.5	30	1.4
S1 (%TST)	16.4	7.1	1.8
S2 (min)	135.5	233.1	-3
S2 (%TST)	39.3	54.9	-2.2
S3 (min)	46.5	34.5	1
S3 (%TST)	13.5	8.1	1.9
S4 (min)	13.5	30.5	-0.7
S4 (%TST)	3.9	7.1	-0.6
SWS (min)	60	65	-0.2
SWS (%TST)	17.4	15.2	0.4
REM (min)	93	93.7	-0
REM (%TST)	27	22	1.1
Movement time (min)	0.5	2.4	-0.7

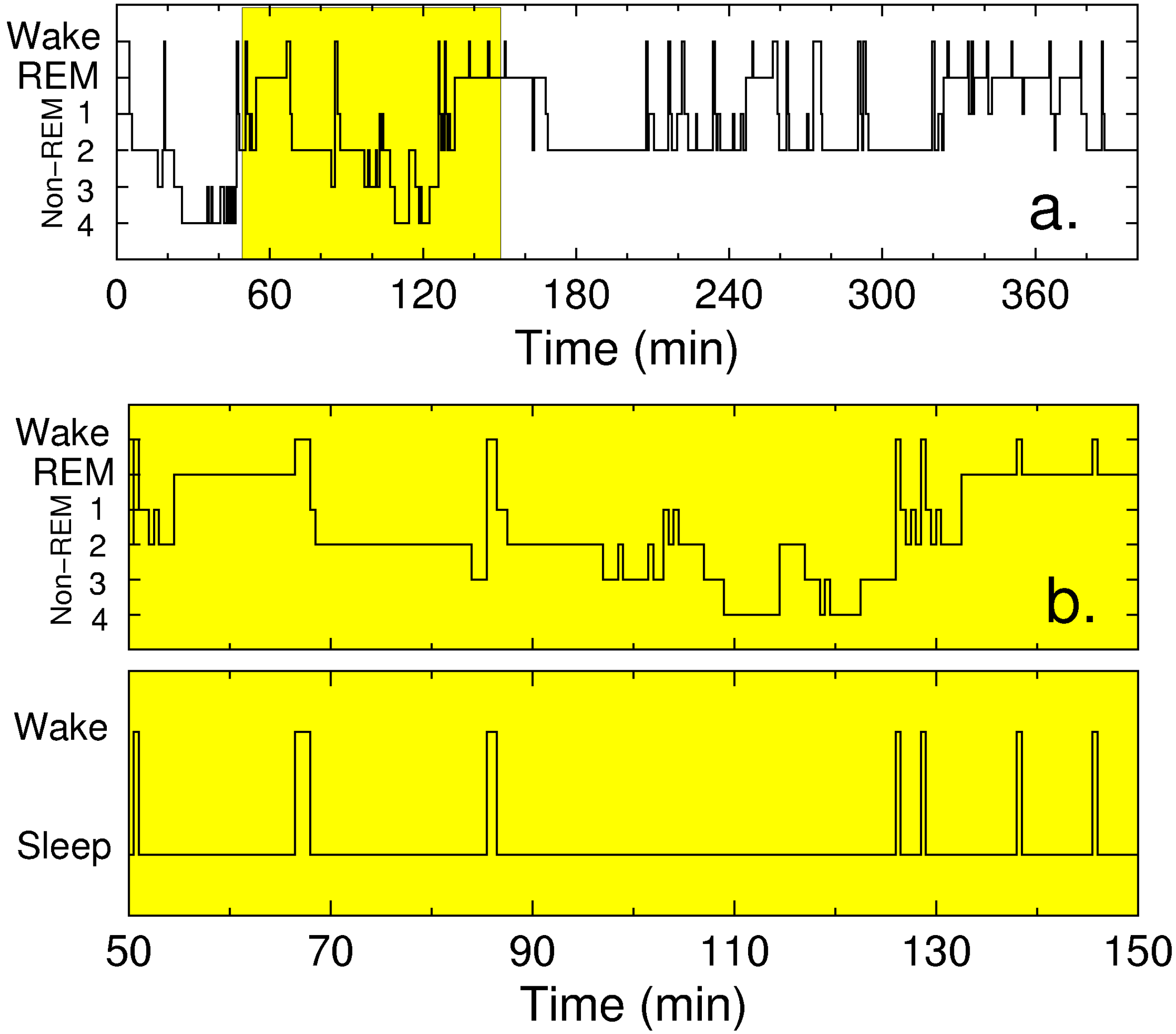
Hypnograms in normal and sleep apnea



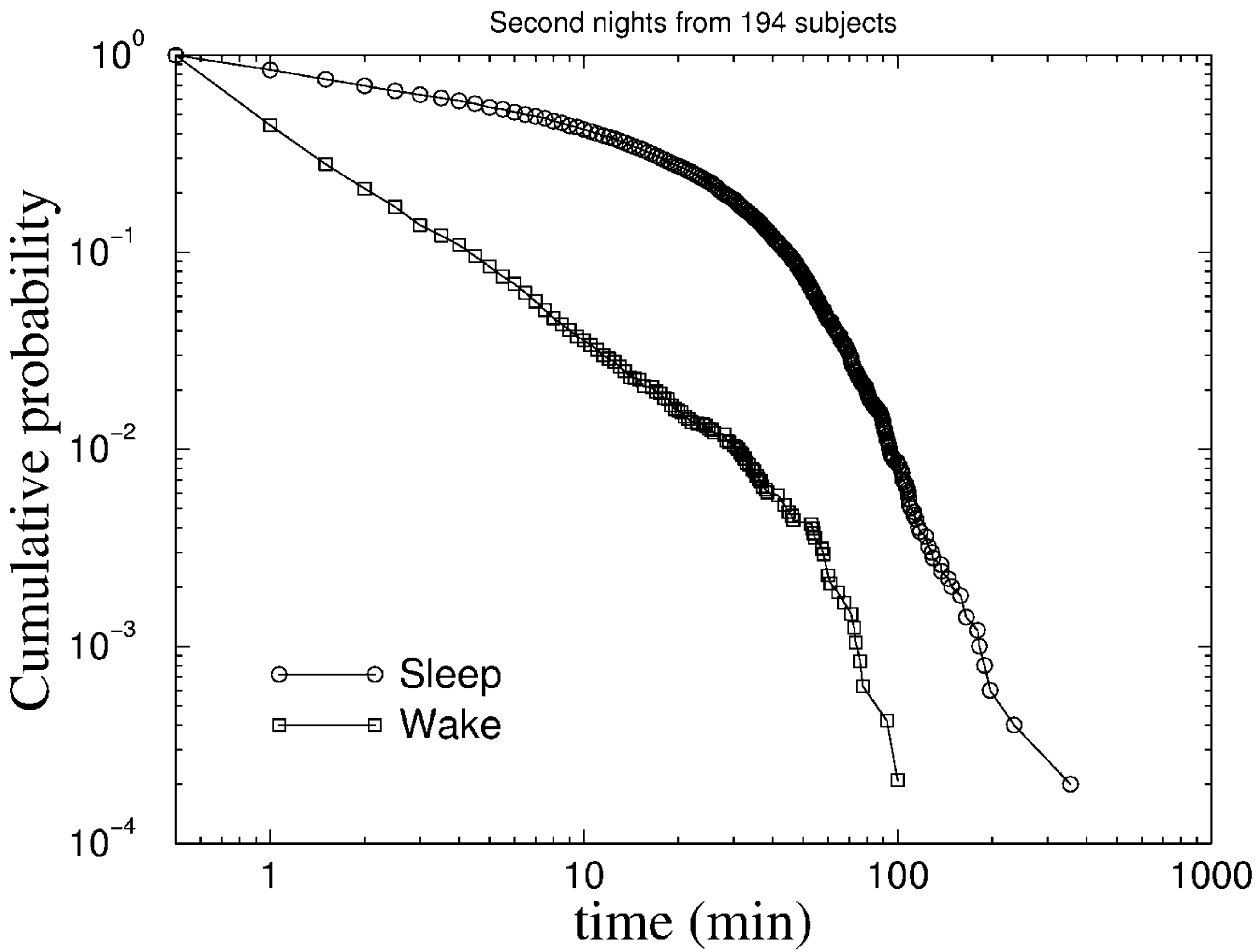
Time spent in sleep stages



Preprocessing of sleep stage classification

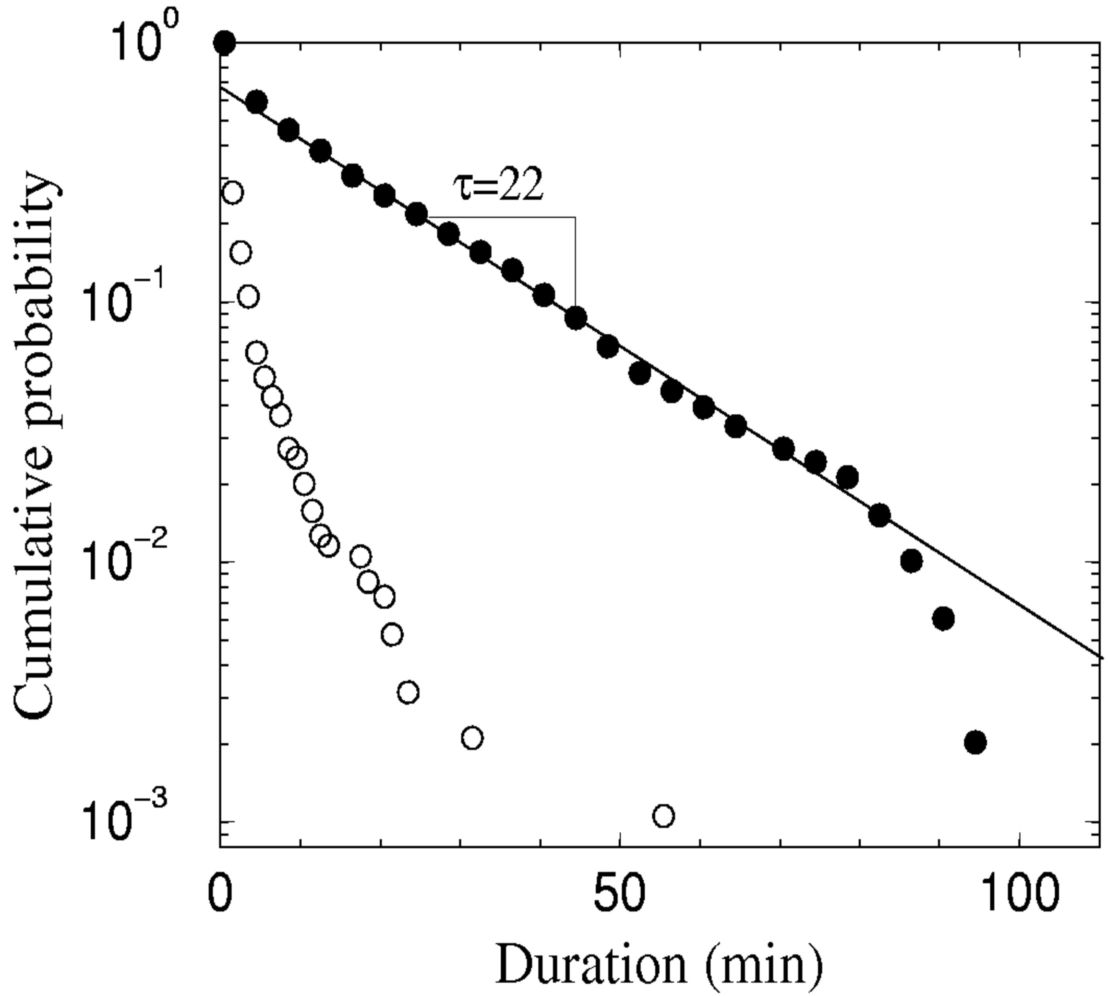


Distribution of wake and sleep over duration



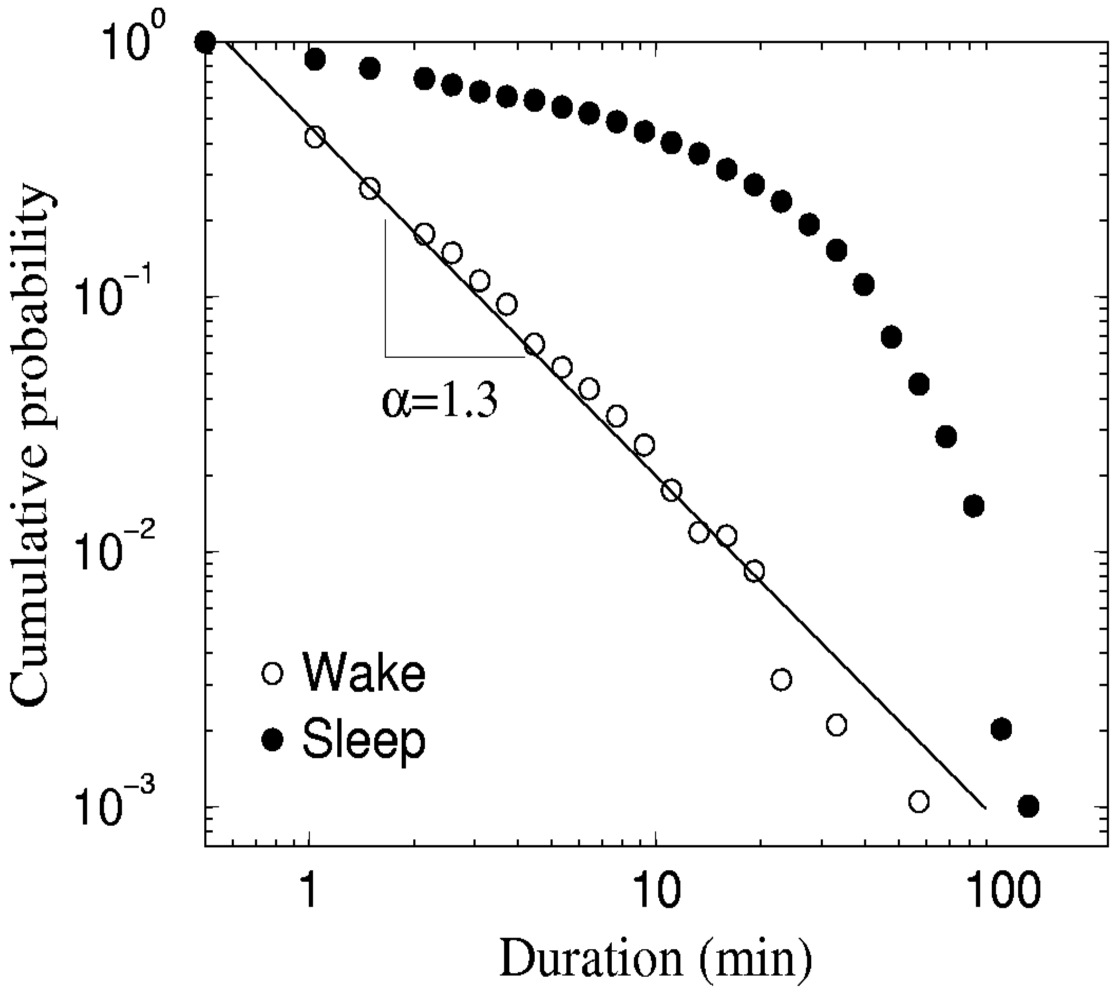
Lo CC, Penzel T: Europhysics Letters 2002; 57: 625-631

Exponential distribution for sleep: $p(t) \sim e^{-\frac{t}{\tau}}$



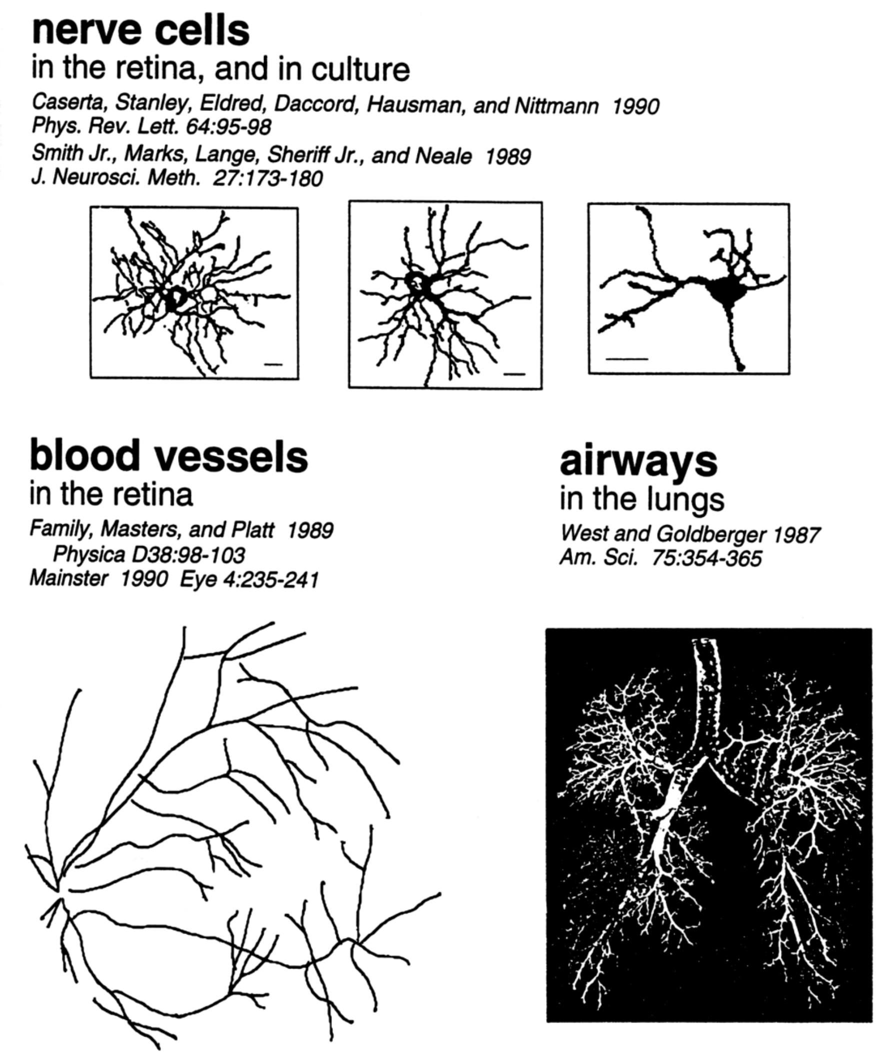
Exponential law is valid for uncoupled random behavior, like throwing a dice

Power law for wake state: $p(t) \sim t^{-\alpha}$



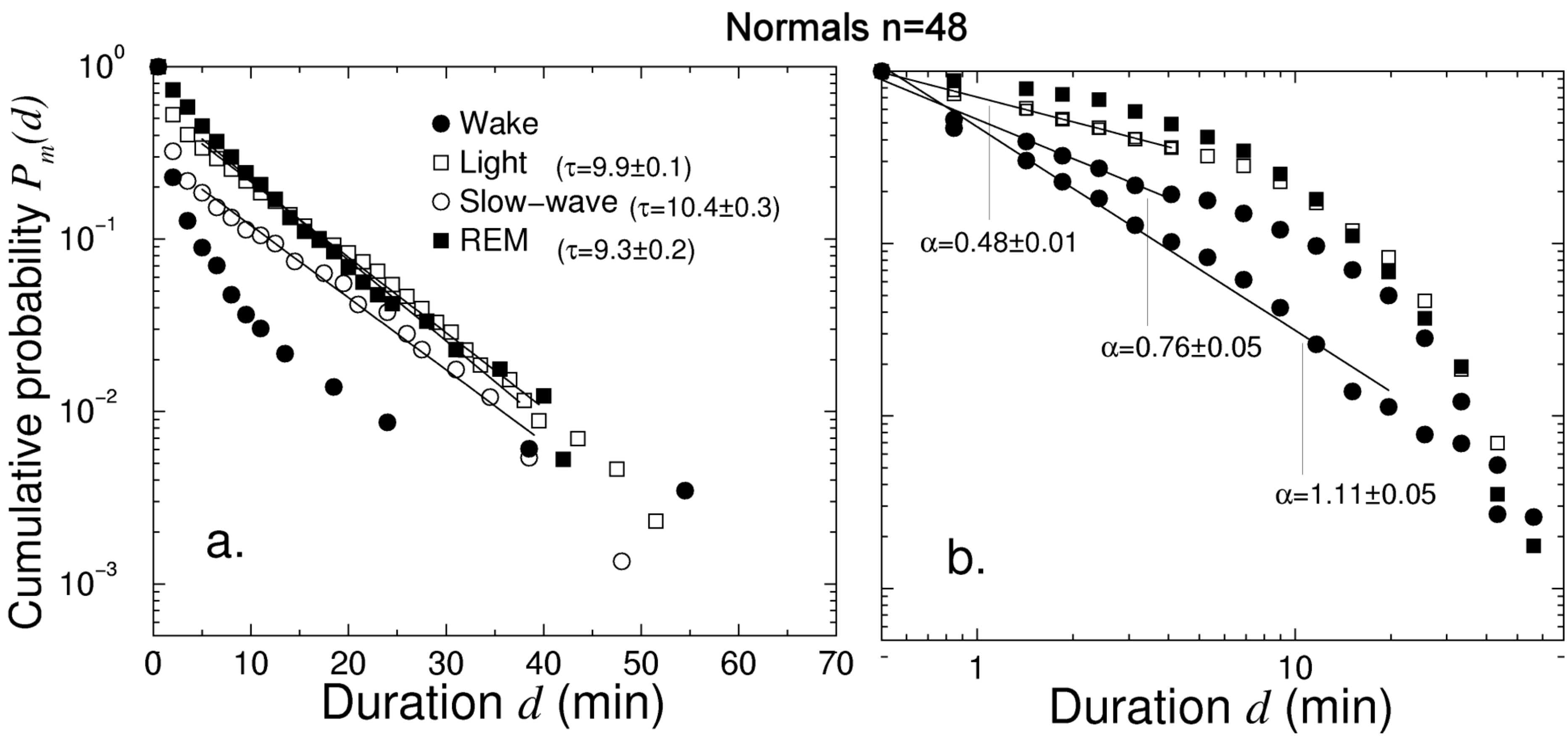
Power law for self similarity in fractals α corresponds to fractal dimension

Power law in general: $p(t) \sim t^{-\alpha}$

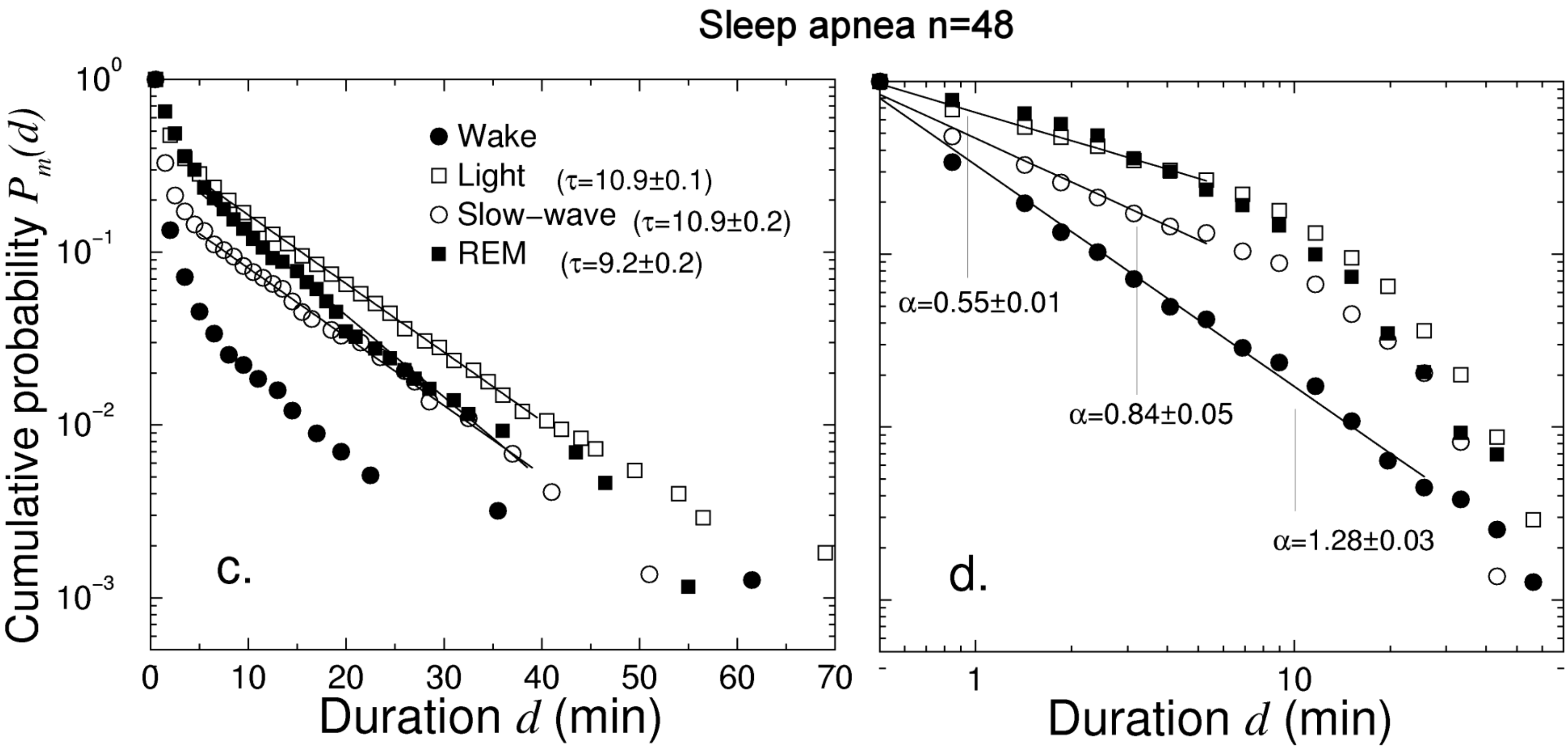


The power law is applicable in fractals. α corresponds to fractal dimension.

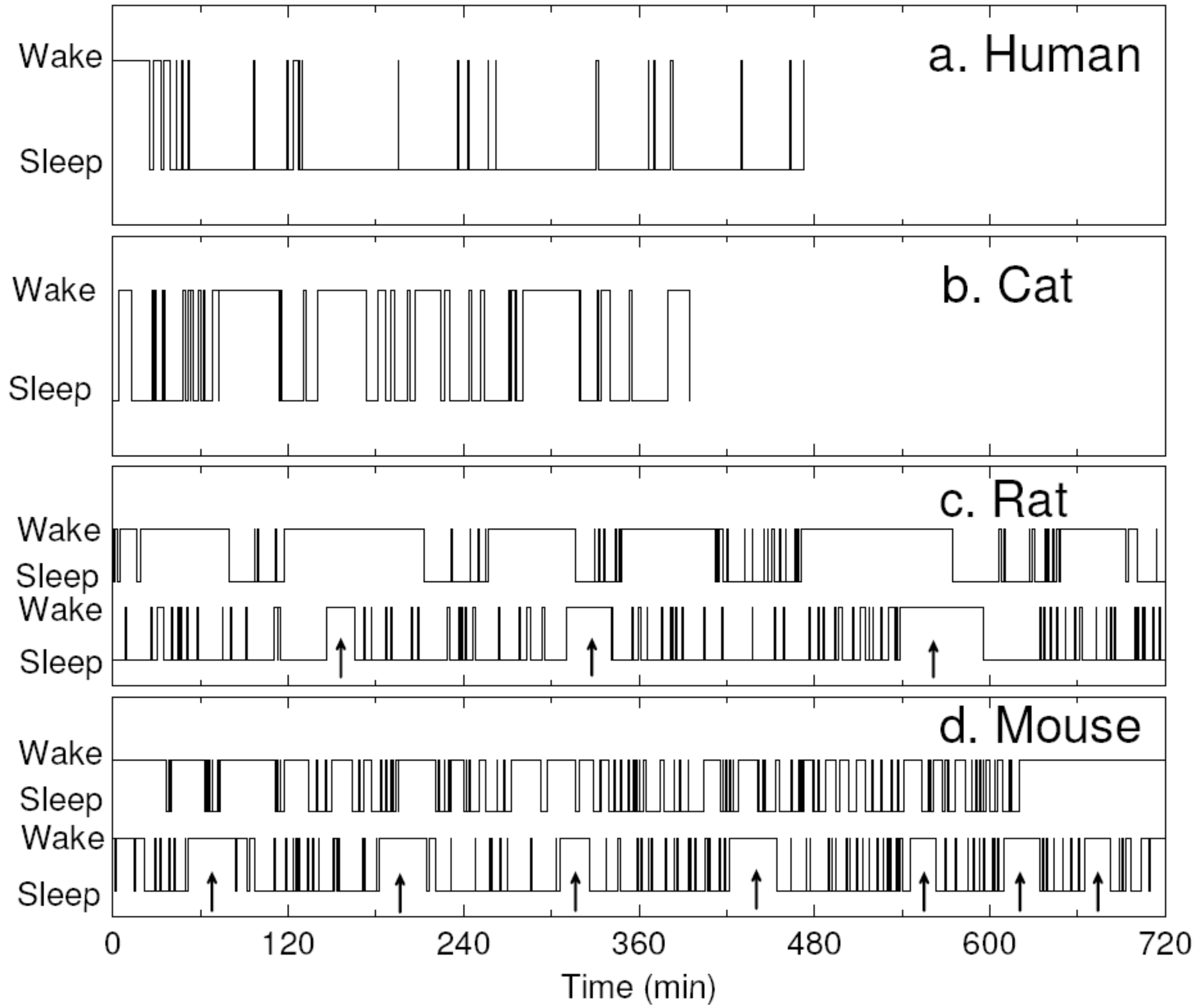
Distribution in normal subjects for sleep stages



Distribution in sleep apnea

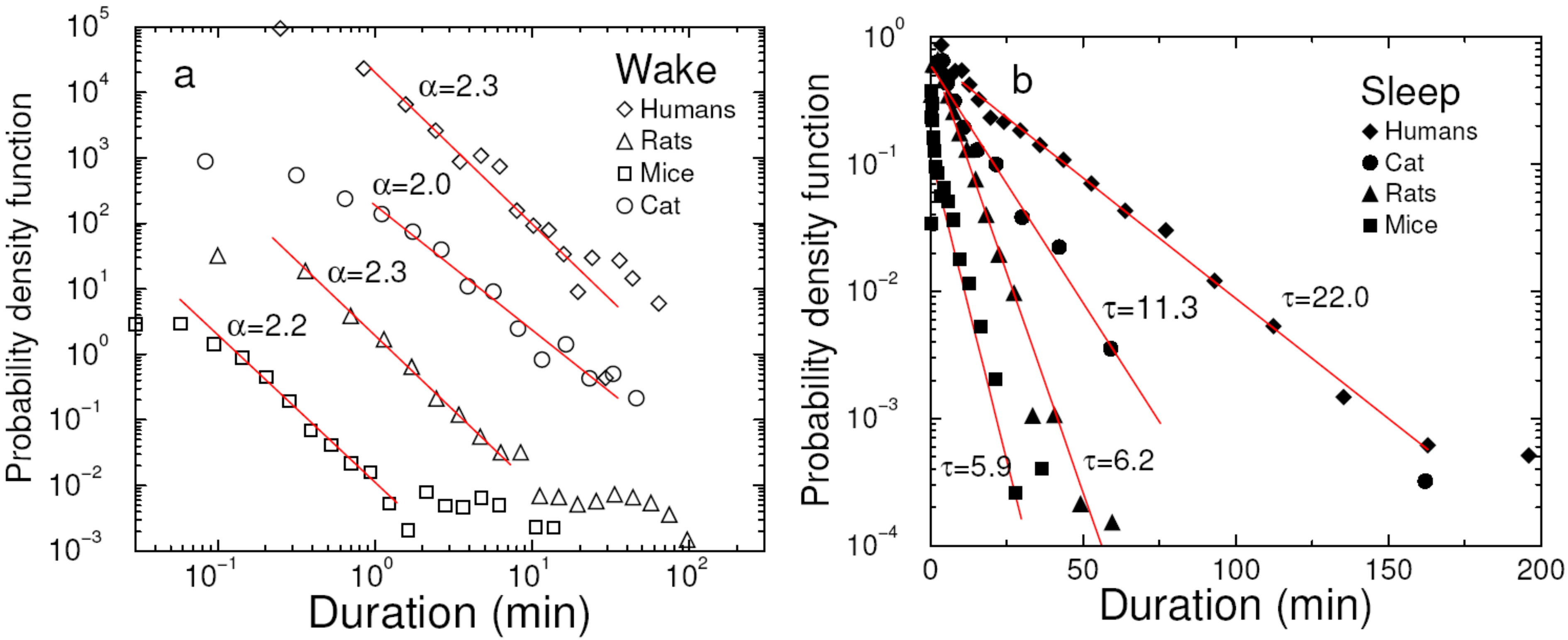


Comparison across species



Lo CC, Penzel T: Proc. Natl. Acad. Sci. 2004; 101: 17545-17548.

Duration of wake and sleep periods across species



Sleep wake transitions in Narcolepsy

ORIGINAL ARTICLE

Nocturnal Dynamics of Sleep–Wake Transitions in Patients With Narcolepsy

Xiaozhe Zhang, MD[1]; Jan W. Kantelhardt, PhD[2,3]; Xiao Song Dong, MD[4]; Dagmar Krefting, PhD[5]; Jing Li, BS[4]; Han Yan, MD[4]; Frank Pillmann, MD[6]; Ingo Fietze, MD[7]; Thomas Penzel, PhD[7,8]; Long Zhao, BS[4]; Fang Han, MD[4]

[1]*Department of Respiratory Medicine, Peking University International Hospital, Beijing, China;* [2]*Institute of Physics, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany;* [3]*Institute of Physics, Humboldt Universität zu Berlin, Germany;* [4]*Department of Pulmonary Medicine, Peking University People's Hospital, Beijing, China;* [5]*Center of Biomedical Image and Information Processing, University of Applied Sciences, Berlin, Germany;* [6]*Klinik und Poliklinik für Psychiatrie, Psychotherapie und Psychosomatik, Martin-Luther-Universität, Halle (Saale), Germany;* [7]*Sleep Medicine Center, Charité Universitätsmedizin Berlin, Berlin, Germany;* [8]*International Clinical Research Center, St. Anne's University Hospital Brno, Brno, Czech Republic*

Introduction: We investigate how characteristics of sleep–wake dynamics in humans are modified by narcolepsy, a clinical condition that is supposed to destabilize sleep–wake regulation. Subjects with and without cataplexy are considered separately. Differences in sleep scoring habits as a possible confounder have been examined.

Aims and Methods: Four groups of subjects are considered: narcolepsy patients from China with (n = 88) and without (n = 15) cataplexy, healthy controls from China (n = 110) and from Europe (n = 187, 2 nights each). After sleep-stage scoring and calculation of sleep characteristic parameters, the distributions of wake-episode durations and sleep-episode durations are determined for each group and fitted by power laws (exponent α) and by exponentials (decay time τ).

Results: We find that wake duration distributions are consistent with power laws for healthy subjects (China: α = 0.88, Europe: α = 1.02). Wake durations in all groups of narcolepsy patients, however, follow the exponential law (τ = 6.2–8.1 min). All sleep duration distributions are best fitted by exponentials on long time scales (τ = 34–82 min).

Conclusions: We conclude that narcolepsy mainly alters the control of wake-episode durations but not sleep-episode durations, irrespective of cataplexy. Observed distributions of shortest wake and sleep durations suggest that differences in scoring habits regarding the scoring of short-term sleep stages may notably influence the fitting parameters but do not affect the main conclusion.

Keywords: sleep–wake dynamics, narcolepsy, cataplexy, sleep scoring, wake-episode durations, power-law distribution, exponential distribution.

Statement of Significance

Previous studies of sleep–wake transition dynamics in healthy humans and mammals revealed that the durations of wake episodes during the night follow power-law distributions, whereas the durations of sleep episodes follow exponential distributions. Here, we study these distributions in larger data sets from narcolepsy patients and healthy subjects. Comparing 4 groups, including data from narcolepsy patients with and without cataplexy and controls from Europe and China, we found that the wake duration distributions are consistent with power laws only for healthy subjects. Wake durations of narcolepsy patients and sleep durations for all subjects rather follow exponential distributions. These findings suggest that the control of wakefulness is altered in narcolepsy patients, reducing the frequency of long wake episodes.

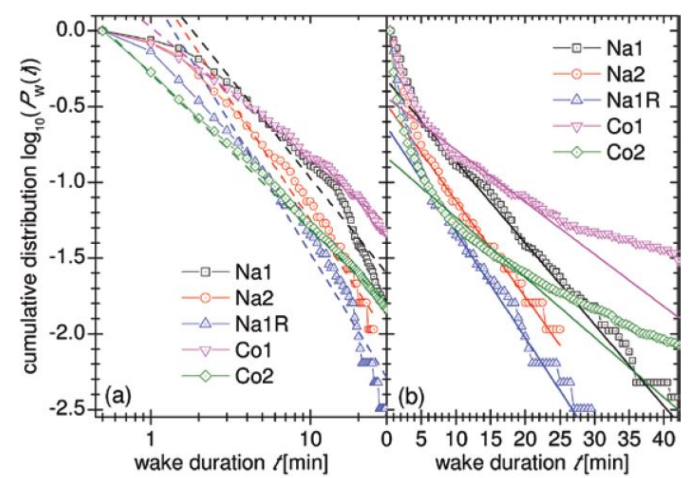


Figure 1—The cumulative distributions of wake durations $P_W(t)$ are shown for 5 groups of subjects (see Methods and legends) in (a) double logarithmic plots and (b) semi-logarithmic plots. The straight-line fits by (a, dashed) $P_W(t) = A\,t^{-\alpha}$ and (b, continuous) $P_W(t) = B \exp[-t/\tau]$ took into account data in the range from t = 2.5 to 25 min. The values of the parameters are reported in Table 2.

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Sleep structure summary

Arousal and sleep fragmentation do reflect the increased central nervous activation in sleep disorders such as sleep apnea

The regulation of the duration of wake (power law) and sleep (exponential law) follow completely different physical laws

The different distribution laws still are maintained in sleep disorders, only the constant values are different

This regulation is similar in different mammals.

This can be achieved only by different neuronal brain centers responsible for the wake and the sleep function (sleep-wake switch)