The Dynamic Structure of NREM Sleep (P.Halász and R. Bódizs) Springer 2012

In this book we provide a new approach to sleep regulation, incorporating the new knowledge of use dependent homeostatic regulation associated with plastic changes during NREM sleep. We amalgamated this homeostatic regulation with the line of the parallel developed micro-structural dynamics driven by sensory impulses from the surrounding world. One of the main lines in the book is the recognition of input dependent (reactive) slow wave activity (responses) incorporated as “instant” homeostatic regulation in the slow wave homeostatic process. Consequently we have shown the state dependency of sleep or arousal promoting effect of sensory input during NREM sleep, and the interdigitation of micro-and macro-level of sleep dynamism. This may explain how the sleeper is kept in contact with the surrounding world preserving the continuity of sleep.

Our scenario for the dynamic NREM sleep regulation can be summarized as follows:
The homeostatic regulation is fed by the synaptic potentiation during the day providing a demand for producing slow waves, allowing synaptic decay. This is the main force of NREM sleep. When the homeostatic pressure is high it drives the hypothalamic sleep promoting neurons to high level of firing. The high firing rate of these neuronal assemblies keeps the wake promoting arousal systems under inhibition. The inhibition of the arousal system liberates the thalamic burst-firing system which produces spindling and slow wave oscillations (Fig. 9.1). In this condition sensory input fuels phasic slow wave activity reflected by the CAP A1 phases, providing slow wave injections to each perturbation of sleep (instant homeostatic regulation) during the ‘D’ slopes characterized by high homeostatic pressure.

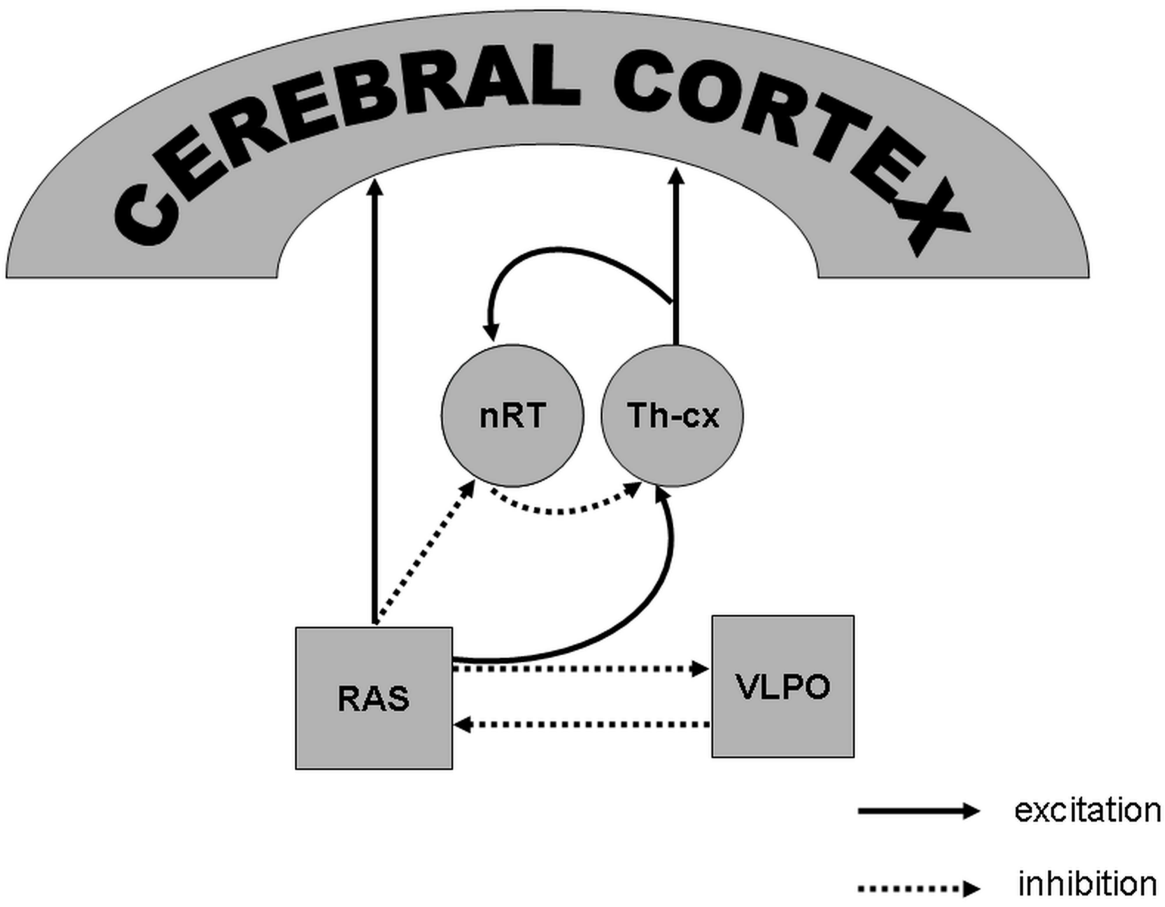

Fig.9.1. Mutual inhibition between the sleep and arousal systems as well as their effect on the thalamocortical circuitry. I. Awake time synaptic potentiation elevates homeostatic pressure, elevating firing rate in VLPO and other sleep promoting neurons. II. VLPO and other sleep promoting neurons inhibit the arousal system (RAS). III. Inhibition of the arousal system liberates the thalamic burst-firing system producing spindle and slow wave oscillation. VLPO

– ventro-lateral preoptic area; RAS – reticular activating system; Th-cx – thalamocortical neurons; nRT – nucleus reticularis thalami; continuous and broken arrows symbolize excitation and inhibition, respectively.
When during decrease of homeostatic pressure (synaptic decay) the firing of the VLPO falls gradually down the impinging sensory input from the external world, reflected by CAP A2-3 phasic events, it starts to bring the sleeper to higher and higher level of arousal along the 'A' slope preparing the next REM sleep (Fig. 9.2).

The co-operation of metabolic demand driven long term homeostatic regulation and the input driven short term phasic arousal-related regulation provide flexible adaptation to accomplish separation from the external world to fulfill trophotropic-, and keep the contact with it for accomplishing ergotrophic activity.

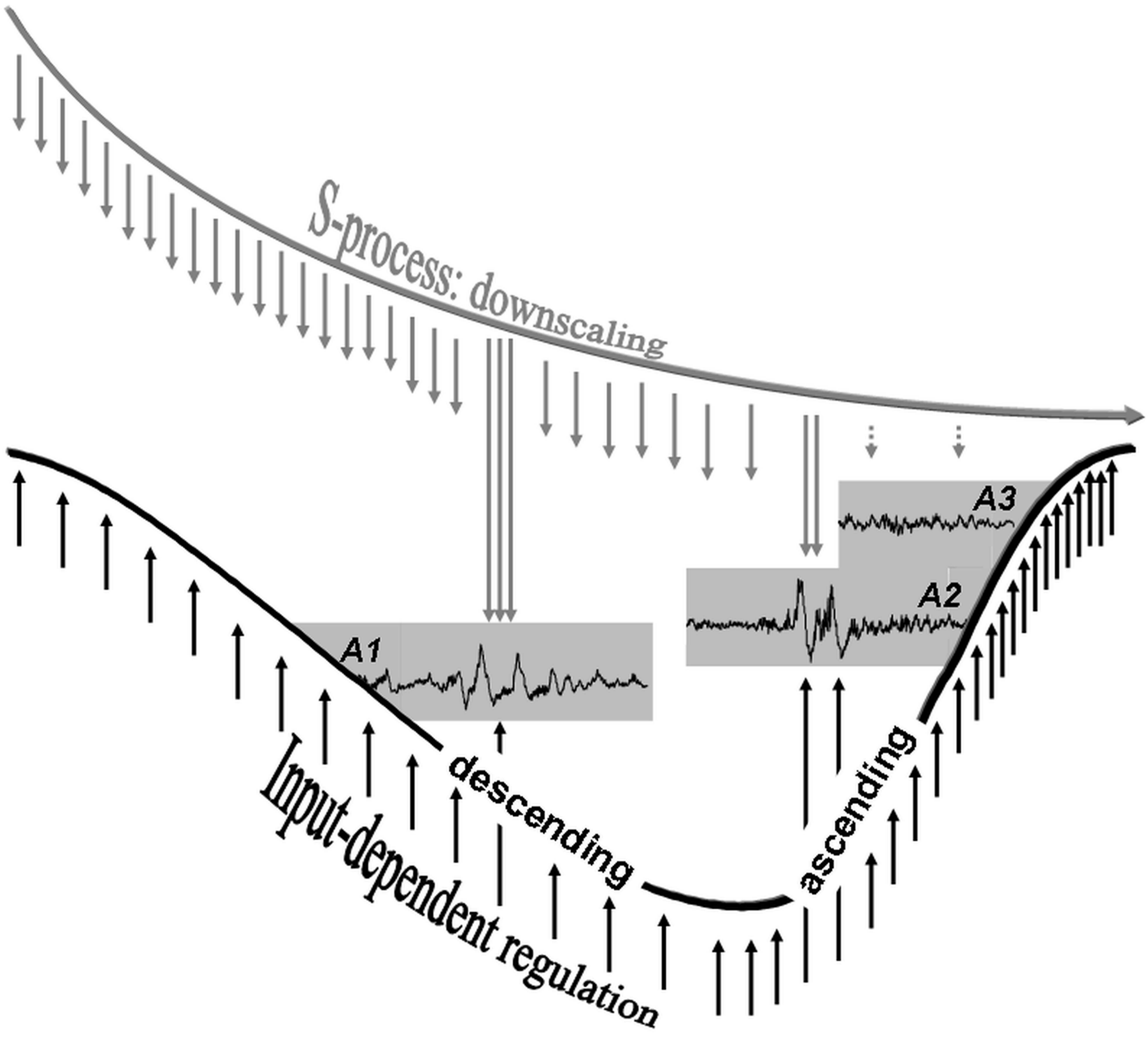

Fig. 9.2. Input dependent phasic sleep regulation during the descending and ascending slopes of sleep cycles under the influence of homeostatic regulation. During the descending slope while homeostatic pressure is high phasic sensory input (black arrows) evokes A1 type sleeplike
responses providing delta injections (grey arrows) and maintaining of sleep. Contrasting during the ascending slope A2 and A3 type responses promote the arousal process and bring the sleeper nearer to the next REM phase that is no more counterbalanced by the decreasing homeostatic pressure.

The same general principle of sleep/wake regulation seems to be represented by the yin-yang alternation of high and low level activity where the high level activity connects the brain with the external world while the low level activity provides separation.
this alternation in the link with the environment can be followed on different levels (Fig. 9.3). First we have sleep and wakefulness as a covering curve of these alternations.

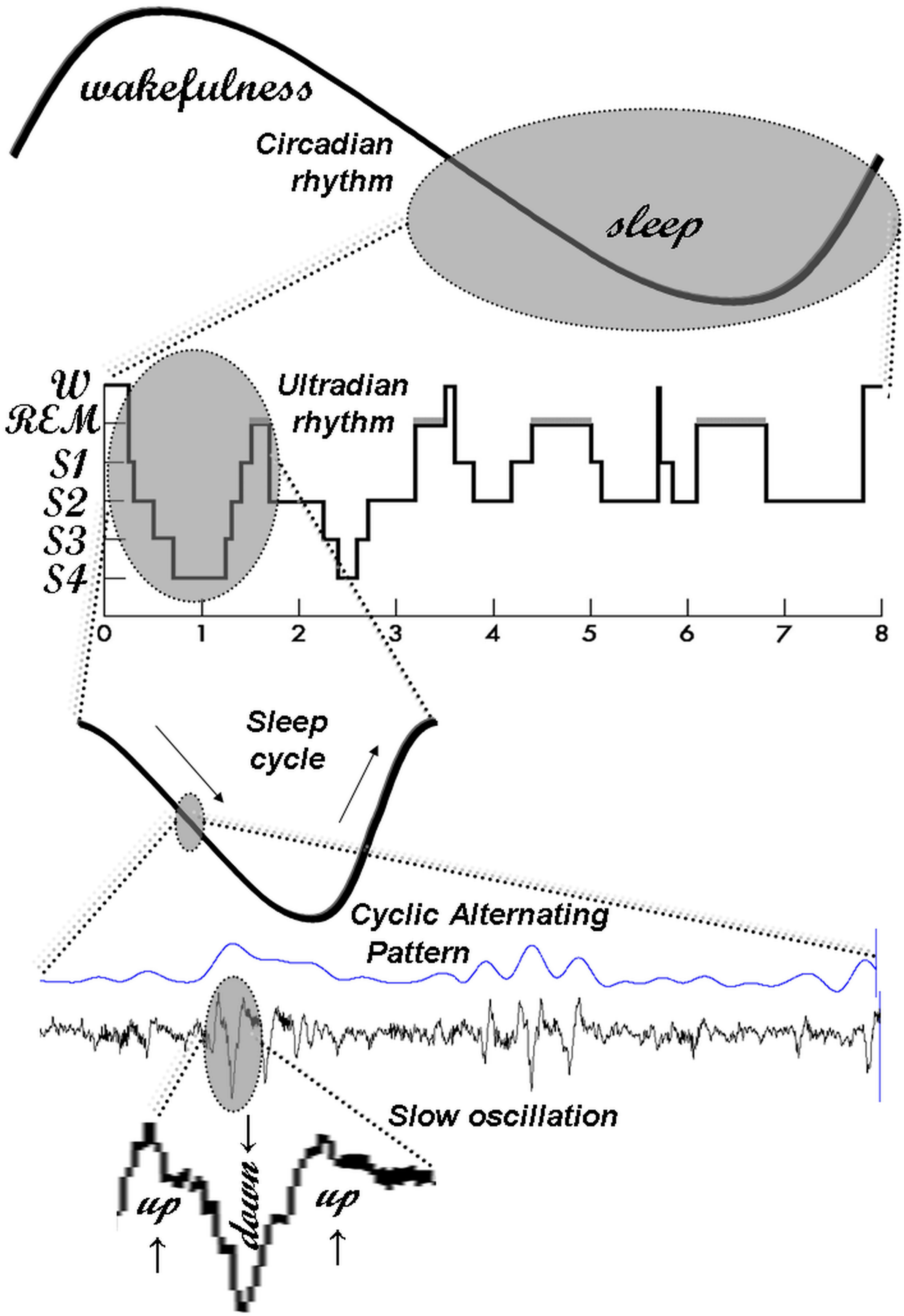
wakefulness
Circadian rhythm
sleep
W
REM
S1
S2
S3
S4
Ultradian rhythm
0
1
2
3
4
5
6
7
8
Sleep cycle
Cyclic Alternating Pattern
Slow oscillation
up
down
up

Fig. 9.3. Yin-yang-like representation of the antagonistic twin principle of connection to and separation from the environment on different levels of sleep/wake continuum. Upper row: within the circadian rhythm waking states alternates with sleep periods. Second row: within the ultradian rhythm in each sleep cycle the descending slope represents sleep promoting conditions and the ascending slope wake/REM promoting conditions. Third row: Cyclic Alternating Pattern represents microstructural activation/inactivation episodes with input related sleep promoting phasic events. Fourth row: < 1 Hz slow oscillation up-and down-states represent within some hundred miliseconds alternating almost wake state like neural/synaptic activation with severe disfacilitation without neural/synaptic activity.

Within sleep we have the sleep cycles with alternation of the ‘D’ and ‘A’ slopes of sleep cycles and the arousal-and sleep-like phasic events in coalescence as smaller grade fluctuations driven by the input factors. Lastly, within slow wave oscillation the up-and downstates realize the same alternation of connection and separation.

The self identical repetition of the alternation of connection and separation on larger and smaller levels show certain resemblance to the dynamics of fractal processes.