RESEARCH ARTICLE

Why Must Sleep Happen?

A Falsifiable Window Thesis, Two Evidence Cartographies, and a Pre-Registered Experiment Agenda

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Background. Why animals must sleep remains unresolved, partly because the field routinely mixes three different questions: what sleep is *for* (function), when sleep becomes *indispensable* (condition), and how sleep *came about* (origin). This paper separates the three and treats them with one shared standard: every claim is either tied to curated evidence or explicitly marked as construction.

Methods. Structured synthesis of a curated, versioned evidence register (109 evidence entries, 294 source records) built under explicit epistemic safeguards — circularity checks, detector-chaining and lab-lineage rules, preprint flagging, and a logged correction practice. All factual claims were verified against retrievable sources; all reference metadata were checked by direct lookup.

Findings. (i) The function question yields a falsifiable construction — the *window thesis* (K13): sleep is the defended state into which state-bound maintenance chemistry retreats because it runs faster there than under wake physiology. Scored clause by clause (P1–P5), three clauses are supported and two remain open; three pre-committed kill criteria are specified. (ii) The condition question is answerable: sleep is *conditionally* essential — essential when the state-bound maintenance debt it clears cannot be carried by wake metabolism without lethal cost; liftable by rewiring, mobilization, and plausibly substitution. (iii) The origin question yields a three-level verdict: *the machine is older than the animal* — the maintenance molecules predate nervous systems, the coupling between cellular state and behavior is only partially documented (one fully measured damage → state → repair chain, lineage-concentrated), and the first coupling is unobservable in principle.

Conclusions. The experiment agenda is pre-registration-ready: F1, a milieu-clamped rate comparison capable of killing the window thesis; E101, its operative near-term version; and E109, a three-stage design for the unresolved ctenophore case — currently a hard evidence void at the phylum level.

Keywords: sleep function; sleep origin; evolution of sleep; DNA repair; homeostatic regulation; falsifiability; ctenophores; cnidarians; adenosine; AMPK

1 Introduction: three questions, one standard

1.1 The function question is not the origin question

Sleep is one of the oldest unsolved problems in biology. Every animal with a nervous system that has been examined carefully shows a sleep or sleep-like state — from mammals and birds to fish, insects, nematodes, and jellyfish[2,50] — and total sleep deprivation is lethal in every species in which it has been sustained long enough, with rats dying within roughly two to four weeks[13,45]. Yet after a century of research there is still no consensus on why this state exists at all[38,44].

We argue that part of the stalemate is a question-management failure. The literature habitually fuses three questions that have different evidence bases, different methods, and different falsification conditions:

- **The function question (why must sleep happen?)** — what does the sleeping state *do* that waking cannot, and why does evolution enforce a state that is so obviously dangerous?
- **The condition question (when is sleep essential?)** — under what physiological or environmental conditions does sleep become indispensable, given that several species can

reduce or suspend it for weeks to months without measurable harm?

- **The origin question (where does sleep come from?)** — which came first: the maintenance chemistry, the state, the coupling between them, or the circadian clock that times them?

A statement that answers one of these questions is routinely used as if it answered the others. Evolutionary arguments ("sleep must be vital because it is universal") are deployed in function debates; molecular findings ("sleep repairs DNA") are treated as origin stories; and the demonstrated *plasticity* of sleep amount is taken as evidence about sleep's *necessity*. The result is circularity: the thing to be explained is quietly built into the explanation.

This paper's first commitment is therefore procedural rather than substantive: the three questions are separated, each gets its own evidence base, and no claim is allowed to migrate from one line to the other without passing the entry criteria of the line it enters. Where we go beyond what the evidence shows, we say so in the text itself, at the sentence where it happens.

1.2 The default audit: what the strongest counter-evidence does and does not show

Any serious proposal about sleep's function must survive what we call the *default audit* — the strongest empirical challenge in the field, associated above all with Jerome Siegel's work[49,50]:

- Species with no predator pressure and no need to catch prey sleep *more*, not less (the brown bat sleeps ~20 h/day), which is hard to reconcile with "sleep exists to keep animals safe and still"[60].
- Some animals function for weeks with drastically reduced sleep: migrating and mating pectoral sandpipers on ~2 h/day for three weeks with peak performance[32]; frigatebirds sleeping less than an hour a day during multi-day flights, then recovering only partially[43]; cavefish populations that have convergently lost most sleep[10]; dolphins and orcas whose mothers and calves show almost no rest behavior for weeks after birth[35].
- Unihemispheric sleep in cetaceans shows that large brains can keep half their cortex awake indefinitely[35] — so "the brain needs sleep" cannot be the whole story; and the comparative literature has long documented species approaching zero measurable rest under specific conditions[26].

The default audit is fatal to naive versions of sleep functionalism ("all sleep loss always costs"). But it is important — and this point recurs throughout the paper — to be precise about what it actually demonstrates. The audit proves **quantity plasticity**: sleep *amount* is astonishingly evolvable, negotiable, and dispensable *for a time*. It does not prove *order plasticity*: no case is known in which the state-bound maintenance processes identified so far are executed at full rate during active wakefulness instead. Even the extreme sleep reducers *keep some sleep*, and the two best-characterized cases of near-total rest suspension (postpartum cetaceans) occur under massive metabolic and hormonal mobilization that has never been mechanistically followed up[35]. The audit constrains every function theory — including ours — but it is not evidence that sleep has no irreducible core. It is evidence about the axis, not about the endpoints.

1.3 Scope and claims of this paper

The paper makes four contributions, in order of decreasing evidential weight:

- **Two evidence cartographies** (Sections 4 and 5): disciplined inventories of what is actually known about the condition question and the origin question, with every entry tied to published evidence and every gap named as a gap. The compressed answers are: sleep is *conditionally* essential (Section 4); and *the machine is older than the animal* (Section 5).
- **One falsifiable construction** (Section 3): the *window thesis* (K13) — a precise, clause-level formulation of why a defended maintenance state would evolve and persist, scored against the evidence clause by clause, with explicit kill criteria.
- **An experiment agenda** (Section 6): three pre-registration-ready specifications — F1, the rate-comparison experiment whose outcome could kill the window thesis; E101, its operative near-term version; and E109, a three-stage design for the unresolved ctenophore case.
- **A worked example of a transparent correction practice** (Section 2.3): the project behind this paper has already publicly corrected two of its own statements — one of them a central discriminator of the origin cartography — when its own audit procedure found them overstated.

The paper's overall stance can be stated in one paragraph. The field does not lack theories; it lacks *discipline about which claims are evidence and which*

are construction. The window thesis is offered as construction — honestly marked, scored, and armed with kill criteria. The cartographies are offered as evidence discipline. If the thesis is wrong, the kill criteria in Section 3.4 are where it dies; the experiment in Section 6.1 is designed to be capable of killing it.

2 Methods: a curated evidence register with safeguards

2.1 Design

This paper distills a structured research project conducted over eighteen documented rounds (plus this synthesis round) between 2025 and August 2026. The project's working instrument is a *curated evidence register*: a versioned inventory of, at the time of writing, 109 evidence entries (E1–E109) and 294 source records (Quellen 1–294), maintained under strict bookkeeping rules[12]. Each entry records: the claim; the source(s) with bibliographic metadata and peer-review status; the evidence class (primary experimental, review, preprint, press); the lineage of the laboratory or laboratories involved; and the entry's status (operative, watch, void, contradiction, superseded).

Sources were identified through iterative web searches against primary literature and review databases. The register is explicitly *curated, not systematic*: inclusion followed the research questions rather than a database protocol (see Section 2.5 for the consequences). Every factual claim in this paper traces to a register entry; where a citation's metadata was uncertain at synthesis time, it was re-verified before inclusion in the reference list. One such re-verification caught a metadata error in our own register (a source recorded with the wrong journal); the register has been corrected and the correction logged[12].

Claims are labeled in-line by epistemic status: *confirmed* (peer-reviewed evidence, register-verified), *watch* (preprint or single unreplicated study), *open* (no direct evidence either way), *void* (searched, nothing found), and *construction* (our own formulation, not evidence). Nothing marked construction is ever cited as support for anything else.

2.2 Epistemic safeguards

The project operates under a standing set of safeguards ("FS rules") that were developed in response to specific failure modes encountered during the work. The ones that matter for reading this paper:

Table 1. Standing epistemic safeguards (selection), with the failure mode each rule addresses

Rule	Content	Failure mode addressed
FS01	Circularity check: no claim may assume the very thing the current question is trying to explain.	Evolutionary universality arguments silently re-entering function debates.
FS04	No cross-detector chaining: two phenomena measured with different detectors in different preparations may not be fused into one "mechanism".	Composite "pathways" assembled from incommensurable experiments.
FS05	Construction marking: own formulations are labeled at the sentence where they occur.	Theory quietly re-reading itself as evidence.
FS08	Lab-lineage rule: convergent findings from the same laboratory (or lineage) count as one house, not independent replication.	Inflated independence counts in the deepest parts of the evidence base.
FS09	Publication-status rule: preprints and press releases are flagged and may support "watch" status at most.	Unreviewed claims hardening into premises.

Two further project rules shape the text. The *no-expansion rule*: the window thesis may not be strengthened by re-framing ("everything is repair"); if the thesis grows, it must grow by evidence. And the *line boundary rule*: the condition cartography (Section 4) does not test the clauses of the window thesis, and evidence may not be back-booked from

one line into the other; likewise, status changes to entries in the origin line pass only through that line's own entry criterion.

2.3 Correction practice

The register is versioned under a standing version rule: superseded text is not deleted but struck through, with the correction marked in place and logged in a change ledger. This matters for one reason: **the procedure has already been used against this project's own central claims.**

The clearest example concerns the origin cartography. In an earlier version, we stated that only one evidence object (O5, the DNA-damage–sleep–repair chain) had a documented *causal transition* from cellular state to behavior. When we later ran a symmetric audit of the energy-sensing object (O2) — applying to our own claim the same standard we apply to the literature — the formulation did not survive: kinase-based transitions between energy state and sleep are documented in both fly and mouse[17,34]. The discriminator was therefore re-specified from "transition" to "*fully measured chain* (damage → state → repair)", which O2 does not meet and O5 does (Sections 5.3). Both the original claim and its correction remain visible in the project documents[12]. We report this not as a curiosity but as a substantive methodological point: an audit practice that cannot catch its owner is decoration.

2.4 AI assistance

The literature searches, register maintenance, drafting, and figure generation in the underlying project were performed by the author working with an AI assistant (Kimi, Moonshot AI). All factual claims entering this paper were checked against retrievable sources; all bibliographic metadata in the reference list were verified by direct lookup; and every interpretive commitment — including the decision to correct our own earlier discriminator — was made and signed off by the human author. A full declaration appears in the Declarations section.

2.5 Limitations of the method

Four limitations deserve emphasis. **First**, the register is curated: it systematically covered the threads it followed, but it did not systematically cover the field; a systematic-review replication could change emphasis and would certainly add entries. **Second**, the source base is English-language and web-retrievable literature. **Third**, the register's strongest deep branches are lineage-concentrated — the deepest part of the origin cartography rests substantially on one research house (Section 5.3, FS08) — and the paper treats that concentration as a fact about the evidence, not an inconvenience to be explained away. **Fourth**, a single-author-plus-AI workflow has no independent human check; the correction practice mitigates but does not eliminate this. We regard publishing the safeguards themselves as part of the result.

3 The window thesis (K13)

3.1 The counterframe: the state is a counter, not a fuel

Before the thesis, a reframing that the evidence forced on us. A natural way to think about sleep is as a *supply state*: the body pumps something up (energy, molecules) or washes something out (metabolites) during sleep, and wakefulness drains it again. Several classical proposals are built exactly on this image, most prominently brain-energy restoration[3,11] and metabolite clearance[57].

The register's pattern points to a different geometry. Across the best-documented cases, what accumulates during wakefulness is not a missing fuel but *structural damage and load* — DNA lesions[1,58,59], oxidative membrane and protein damage[28,54] — and what the sleep state provides is not fuel but a *window*: a defended physiological milieu in which the cell's standing maintenance chemistry can run at a rate that wake physiology does not permit. Damage is the counter that drives the homeostat; repair is what happens in the window; and the lethal endpoint of total deprivation looks less like running out of fuel than like unbounded damage accumulation[13,54]. This counterframe — *counter, not state-as-fuel* — is itself an evidence-grounded reframing and recurs throughout Sections 4 and 5.

3.2 Formulation

The window thesis, in its current frozen formulation (project designation K13; *construction* in the sense of Section 2.1):

Sleep is the defended state into which state-bound maintenance chemistry retreats, because it runs there faster than under wake physiology — for the set of processes that are state-bound at all. The homeostat that enforces the state is coupled to the damage that accumulates outside the window, not to time or tiredness per se.

Three properties of the formulation matter. **First**, it is a *rate claim*, not an exclusivity claim: maintenance chemistry also runs during wakefulness; the thesis says the *rate* is higher in the window for the state-bound subset. **Second**, it is *restricted*: it says nothing about processes that are not state-bound (e.g., much of synaptic plasticity may proceed in both states; Section 7.3) — the no-expansion rule forbids inflating the claim to "everything is repair". **Third**, it is *decoupled from clock architecture*: it predicts a defended maintenance state, not necessarily a circadian one; circadian timing is a later add-on (Section 5).

The thesis decomposes into five testable clauses:

- **P1 (window advantage).** For state-bound processes, the repair/clearance rate is higher in quiet wake or sleep than in active wake under matched milieu conditions — a *state effect*, not merely a time effect.
- **P2 (damage coupling).** The homeostat's drive signal is coupled to accumulated cellular damage, not only to time awake.
- **P3 (effector execution).** During sleep, the relevant maintenance effectors actually execute (repair, clearance, membrane turnover).
- **P4 (homeostat necessity).** The homeostat machinery is necessary for survival under conditions where damage cannot otherwise be kept below lethal bounds.
- **P5 (homeostat existence).** A dedicated, identifiable homeostat exists that senses state, integrates debt, and drives the state transition.

3.3 Scoreboard: clauses P1–P5

Table 2 scores each clause against the register. The scoring standard is deliberately asymmetric in the conservative direction: a clause is "supported" only if the register contains direct, peer-reviewed evidence for the clause as stated, not for a neighboring claim.

Table 2. Clause scoreboard for the window thesis (as of August 2026). Status: supported = direct peer-reviewed evidence for the clause as stated; open = no direct evidence either way

Clause	Content	Status	Basis
P1	Rate advantage of the window (state effect on repair rate, milieu-matched)	**Open**	No clean rate comparison between quiet wake and sleep under clamped milieu exists for any state-bound process. Nearest evidence: chromosome dynamics increase with sleep[58]; but design confounds (stress of deprivation, milieu differences) are uncontrolled. Directly tested by experiment F1 (Section 6.1).
P2	Drive coupled to damage, not time	Supported	DNA damage modulates sleep drive in cnidarians[1]; PARP1 marks damage and promotes sleep in zebrafish neurons[59]; mitochondrial redox state gates a dedicated sleep-promoting potassium-channel switch in the fly[28]; sleep-loss lethality tracks gut ROS accumulation[54].
P3	Effectors execute during sleep	Supported	DNA repair enhanced in sleep[59] and damage reduced across natural sleep in single neurons[58]; glymphatic metabolite clearance strongly state-dependent[57]; brain ATP rises during sleep, consistent with anabolic/maintenance predominance[11].

P4	Homeostat necessary for survival	**Open**	No deprivation design has ever been demonstrated stress-free; the classic lethal-deprivation result[13] cannot separate "homeostat necessary" from "deprivation method lethal" (bacterial invasion documented in the same paradigm[4]). Kill criterion D3 defines what would count (Section 3.4).
P5	Dedicated homeostat exists	Supported	Molecularly identified sleep-need integrators: salt-induced kinases (SIK in worm[17]; SIK3 in mouse by forward genetics[15]); the dFB redox switch[28]; LKB1 required for sleep from fly to mouse[34]; the adenosine system in mammals[41].

Two honesty constraints on the scoreboard. **First**, the P5 evidence comes with a registered counter-example: in *Drosophila*, the classic mammalian somnogen adenosine does *not* mediate sleep homeostasis — deletion of the single fly adenosine receptor leaves sleep and rebound intact, and caffeine acts via PKA instead[56]. Adenosine is therefore a mammal-line effector, not a universal one; the thesis claims a homeostat, not a particular molecule. **Second**, an honest contradiction is permanently registered: locus-coeruleus lesions in rat fail to abolish slow-wave homeostasis[7], constraining any simple "arousal-system-off is the window" reading. We do not resolve this contradiction; we register it.

3.4 Kill criteria

A thesis that cannot be killed is not a contribution. The window thesis carries three pre-committed kill criteria:

- **D1 — the rate kill.** Clause P1 is shown *fully negative*: in clean, milieu-clamped quiet-wake-versus-sleep rate comparisons, no state advantage appears across the material candidate classes. Operational specification (project workshop, single marked stipulation): "fully negative" means at least two of the three material candidate classes — DNA repair, membrane-lipid turnover, protein turnover — negative at the design quality specified in experiment F1 (Section 6.1).
- **D2 — the effector kill.** All homeostat effectors identified under P3 prove to be purely neural — i.e., the state-bound maintenance set is empty at the cellular level and the thesis's subject matter does not exist.
- **D3 — the essentiality reversal.** Replicated lethality under *demonstrated stress-free* total deprivation (P4) is combined with evidence that the lethal mechanism is unrelated to maintenance-debt accumulation — reversing the counterframe's core prediction about what kills sleep-deprived animals[13,54].

D1 is the strongest criterion because it tests the clause that is currently open and central — and because it is executable with present technology (Section 6.1). Note the asymmetry the criteria encode: the thesis dies on *rate* evidence, not on amount plasticity. Cavefish losing sleep[10] does not kill it (quantity); sandpipers outperforming on 2 h/day[32] does not kill it (quantity, time-limited); a demonstrated absence of any state-dependent rate advantage in a clean design kills it outright (order). This is the same distinction the default audit forces (Section 1.2), applied to ourselves.

3.5 Boundaries: what the thesis does not claim

Explicitly, K13 does not claim: that all sleep functions are maintenance (the synaptic-homeostasis and memory literature stands on its own evidence[14,53]); that sleep is the only maintenance window (torpor, hibernation, and quiet wake are neighboring windows; see the energy-allocation framework[47]); that the homeostat is one molecule or one nucleus (the register's P5 evidence is multi-system[15,17,28,34,41]); or that the thesis explains REM/NREM architecture (a late, lineage-specific elaboration outside the thesis's scope[2,23]). The thesis also does not claim that the window is *why we dream*, why sleep feels good, or why it is timed at night — those are the clock's and the cortex's questions, not the window's.

4 Cartography I: when is sleep essential?

The condition question asks something narrower than the function question: not "what is sleep for?" but "*under what condition does sleep become indispensable?*" The question is forced by the default audit (Section 1.2): if sleep were unconditionally essential in a simple dose sense, the documented reductions — weeks of near-wake in postpartum cetaceans[35], convergent sleep loss in cavefish[10], peak performance on 2 h/day in sandpipers[32] — should not exist. They do exist. So the essentiality of

sleep must be *conditional*, and the cartography's job is to map the condition.

The cartography is governed by its own line boundary (Section 2.2): it does not test the window thesis's clauses, and none of its entries are back-booked as evidence for K13. Its compressed answer stands independently of whether K13 survives.

> **Answer form (condition question).**
>
> Sleep is not unconditionally essential. It is essential under the condition that the state-bound maintenance debt it clears cannot be carried by wake metabolism without lethal cost. That condition is real in most animals most of the time — and it is liftable: by rewiring (cavefish), by time-limited mobilization (sandpipers, postpartum cetaceans), and plausibly by pharmacological substitution (nobody has tried). The evolutionarily enforced thing is not a dose; it is a clearing condition.

The cartography rests on seven evidence classes, each documented in the register with peer-reviewed anchors:

Table 3. Cartography I — the seven evidence classes of conditional essentiality (anchors; full entry set in the register[12])

Class	What the class shows	Anchor evidence
1 Lethality of total deprivation	Sustained total sleep deprivation is lethal in rat within weeks, with a damage-accumulation phenotype; mechanism confounded by method stress (bacterial invasion documented)	Rechtschaffen/Everson paradigm[13,45]; confound[4]; fly gut-ROS lethality[54]
2 Damage-coupled drive	Sleep drive tracks cellular damage, not just time awake	Cnidaria[1]; zebrafish PARP1[59]; worm stress-sleep (SIS)[20]
3 Protective stress-sleep	An ancient, conserved program induces sleep after cellular stress and improves survival — sleep as emergency maintenance window	*C. elegans* SIS via ALA/EGF[20,29]; p53/cep-1 dependence[9]; lethargus[42]
4 Plasticity of amount	Sleep amount is strongly evolvable and conditionally reducible without measured harm — the class that kills unconditional dose-essentiality	Sandpipers[32]; frigatebirds[43]; cavefish[10]; cetaceans[35]; human natural short sleepers (DEC2)[19]
5 Consequences of disruption	Even without total deprivation, disrupting sleep's deep phases has measurable maintenance costs	CSF amyloid-β after slow-wave disruption[24]; NREM slow waves and memory in aging[37]; developmental plasticity[14]
6 Energy-state coupling	Sleep pressure is gated by cellular energy state — the maintenance window opens on metabolic terms	ATP rise in sleep[11]; AMPK manipulation shifts sleep depth[6]; LKB1[34]; SIK[17]; energy-restoration framework[3]
7 Homeostat machinery	Dedicated molecular integrators of sleep need exist and are conserved — the enforcement apparatus of the condition	SIK3 forward genetics[15]; dFB redox switch[28]; adenosine system (mammal line)[21,41,51]; fly boundary[56]

Three structural properties of the map deserve emphasis:

- **Asymmetry.** The classes that establish essentiality (1–3) and the classes that establish plasticity (4) are not contradictory; they bound each other. Sleep is lethal when denied *and* dispensable when compensated — the condition, not the dose, is the invariant.
- **Age.** The protective stress-sleep class (3) is functionally documented in a nematode[9,20], placing the coupling between cellular damage and behavioral quiescence deep in animal phylogeny — a bridge to the origin cartography (Section 5).
- **The named lift-condition.** Every documented lifting of essentiality comes with an identifiable substitute: ecological rewiring (cavefish populations independently losing sleep[10]), time-limited metabolic mobilization (sandpipers[32], cetaceans[35]), or genetic rewiring of the homeostat itself (DEC2 short-sleepers[19]). The

pharmacological substitution arm — carrying the maintenance debt pharmacologically during enforced wake — has never been attempted in a controlled design; it is registered as a named gap[12].

The cartography closes with its own decision criterion (project designation G5): the question "when is sleep essential?" is considered answered unless future evidence either (a) demonstrates a case of *unconditional, condition-free* sleep essentiality at the cellular level, or (b) demonstrates a case of *full, indefinite, uncompensated* sleep absence in a normal animal. Neither exists in the register.

5 Cartography II: where does sleep come from?

The origin question is the deepest of the three and the one with the thinnest evidence — which is precisely why it needs the most discipline. What is actually documented, and in what order did it appear? The cartography's answer, compressed: **the machine is older than the animal.**

5.2 The time axis

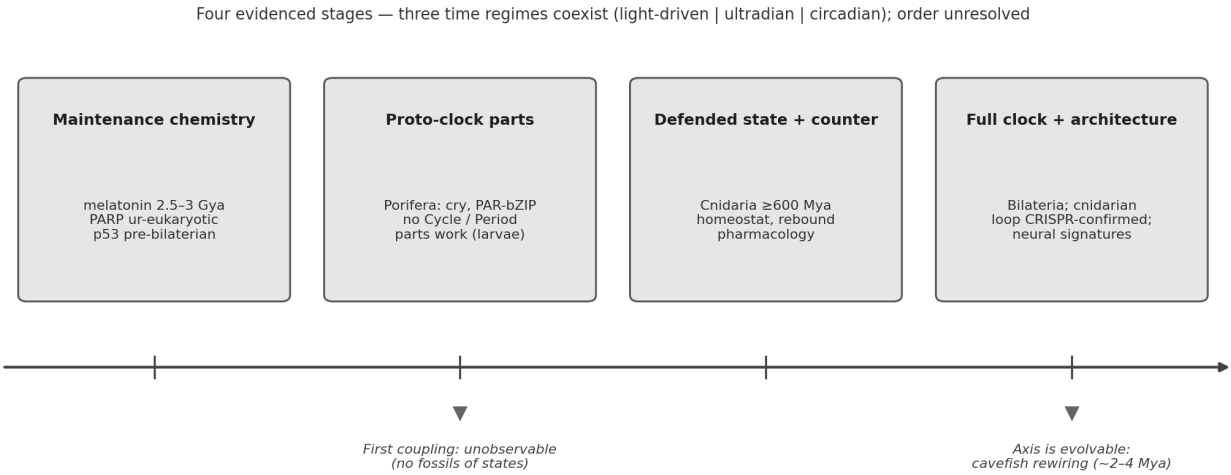

Figure 1. The four evidenced stages of sleep's deep history. Three time regimes coexist in the same animals (light-driven behavior; ultradian cycles; the circadian clock), and the *order* of the stages is only partially resolved: maintenance chemistry and proto-clock parts predate nervous systems; the defended state with its damage counter is documented at the base of animals with nerve nets; full clock-plus-architecture coupling is a later, lineage-specific build. The first coupling between cellular state and behavior is unobservable in principle (Section 5.5). The axis itself is evolvable: cavefish populations rewired their sleep in roughly 2–4 million years[10].

Four stages are evidenced — and the discipline consists in keeping them separate:

1. **Maintenance chemistry** (older than animals, arguably older than eukaryotes): DNA repair, redox defense, and the energy-sensing machinery are ancient. The AMPK/TOR nutrient-sensing axis is traceable across all three domains of life[46]; the aldo-keto reductase superfamily is primordial[22]; melatonin, now the molecular signal of darkness that gates sleep timing in fish and mammals[16], originated as a free-radical scavenger an estimated 2.5–3.5 billion years ago[36,52].
2. **Proto-clock parts** (pre-neural): clock-gene components are present in ctenophores and cnidarians but absent in sponges and *Trichoplax* — a mosaic, not a ladder[39,48]; and below the circadian layer, ultradian behavioral oscillators of dopaminergic origin run on yet another regime[5].
3. **The defended state with its counter** (documented at the nerve-net base): sleep-like states with homeostatic rebound exist in cnidarians[25,40], and DNA damage modulates their drive[1].
4. **Full clock + architecture** (late): circadian gating, REM/NREM differentiation, and unihemispheric variants are lineage-specific builds on top of the older stack[2,23,27].

5.3 Six evidence objects (O1–O6)

The cartography is organized into six evidence objects, each with a registered verdict. Table 4 gives the compressed map; the two objects that carry the argument (O2, O5) are discussed below.

Table 4. Origin cartography: six evidence objects with verdicts (register-anchored[12])

Obj.	Content	Verdict	Key anchors
O1	Maintenance molecules predate animals	Strong — molecules carry the deep end	AMPK/TOR[18,46]; AKR[22]; melatonin antiquity[36,52]
O2	Energy-state → behavior transition	Transition yes; full chain no; depth no	LKB1 fly+mouse[34]; AMPK pharmacology[6]; SIK/SIK3[15,17]
O3	Defended state + damage counter	Strong at nerve-net base	Cnidaria damage-drive[1]; worm stress-sleep[9,20]; fly redox switch[28]
O4	Clock coupling	Mosaic; late relative to state	Ctenophore clock parts[39,48]; cnidarian sleep[25,40]
O5	Damage → state → repair: the full chain	**Only object with a fully measured chain**	Zebrafish neuron imaging[58,59]; cnidaria drive[1]; review[31]
O6	Sleep architecture (REM/NREM etc.)	Late, lineage-specific	Reviews[2,23,27]; zebrafish signatures[33]

O5 is the cartography's load-bearing object. In zebrafish neurons, DNA damage accumulates during wakefulness, chromosome dynamics increase during sleep in a way that enables damage reduction, the damage-sensor PARP1 promotes sleep, and sleep enhances repair[58,59] — and in cnidarians, representing the nerve-net base, DNA damage modulates sleep drive in species with divergent chronotypes[1]. Damage → state → repair is, end to end, the only fully measured chain in the origin line.

Two discipline notes, both carried openly. *First (FS08):* the deep end of that chain — cnidaria, zebrafish, and the mouse-side follow-ups — comes substantially from one research house (the Appelbaum/Bar-Ilan lineage). Independent arms exist (worm: p53-dependent stress-sleep[9]; fly: two independent houses[12]; melatonin: two houses[36,52]), but the deepest single chain is one-house evidence, and this paper says so wherever O5 is used. *Second (symmetric audit):* the O2/O5 discriminator printed here is the *corrected* one. An earlier version distinguished O5 as the only object with a documented causal *transition*; the project's own audit (Section 2.3) showed the transition is also documented for O2 (LKB1 loss-of-function reduces sleep in both fly and mouse, with a LKB1×AMPK interaction[34]). The surviving discriminator is chain *completeness*: O2 has transition but neither a measured repair endpoint nor depth at the cnidarian base; O5 has all three.

5.4 The ctenophore void

The cartography's sharpest negative result concerns the phylum that may hold the oldest animal nervous system. Ctenophores are candidates for the sister lineage of all other animals; their nervous system lacks serotonin, dopamine, noradrenaline, octopamine, and nitric-oxide signaling — the entire classic arousal/sleep transmitter set — is glutamatergic, comprises roughly ten thousand neurons, and may have evolved independently of ours[39]. If that is so, ctenophore sleep (if it exists) would be a *second experiment of nature*: an independent origin of the state, against which everything else in this paper could be tested for contingency.

What exists in the literature: exactly one behavioral study — an unreviewed preprint reporting ~74% "drifting" behavior in *Pleurobrachia pileus*, light-phase only[8]. Against it stands a confounder the cartography names as its methodological result: *Pleurobrachia* is an ambush predator; "sit-and-wait drifting" is a foraging mode, and quiescence in an ambush predator cannot be distinguished from hunting without an arousal-threshold measurement. Two independent null searches (no deprivation study, no arousal-threshold study, no dark-phase videography anywhere in the phylum) confirm a **hard void**: ctenophore sleep is currently undecidable, and any claim about "sleep in all animals" that silently includes ctenophores is unproven[12]. The experiment specification E109

(Section 6.3) defines the three stages that would settle it.

5.5 Answer form: the machine is older than the animal

> **Answer form (origin question), three-level verdict.**
>
> **Level 1 — the molecules carry.** The maintenance chemistry and energy-sensing machinery that make sleep work today are older than animals; melatonin predates the nervous system by billions of years[18,22,36,46,52].
>
> **Level 2 — the coupling is partially documented.** Exactly one full chain (damage → state → repair) is measured end to end, and its deep end is one house (O5); the energy-state transition is documented but chain-incomplete (O2); stress-induced protective sleep is documented at worm depth[9,20].
>
> **Level 3 — the first coupling is unobservable.** The event that first tied cellular state to organism-wide quiescence left no traceable record: the lineages that could show it alive today are exactly the ones (sponges, placozoans) that lack the state, and the ones that have it (cnidarians, ctenophores) lack the transition's record. This is not a temporary gap; it is a principled observability limit of the question.

Two closing symmetries. The default audit applies here too: the demonstrated evolvability of the axis (cavefish rewiring within a few million years[10]) proves quantity plasticity at evolutionary depth — it does not reorder the stages. And the origin cartography, like the condition cartography, is closed under its own criterion: it has no K14-style open question pending, because its residue (Level 3) is unobservable rather than unresearched.

6 Experiment agenda

A synthesis that ends in "more research is needed" is worth little. The project therefore commits to three concrete, pre-registration-ready experiment specifications. The first is designed to be capable of killing the window thesis; the second is its operative near-term version; the third settles the ctenophore void. All three specify their branching logic *before* any result is in.

6.1 F1: the rate comparison that can kill the thesis

F1 tests clause P1 — the open, central clause — directly: *does state-bound maintenance run faster in the sleep window than in quiet wake, when the milieu is clamped?*

Table 5. F1 design parameters (full specification in the project workshop document[12])

Parameter	Specification
Question	Is there a *state effect* on maintenance rate (sleep vs. quiet wake) under matched physiological milieu — or is the apparent window advantage entirely a milieu/time effect?
Organisms	Mouse (primary) and *Drosophila* (replication arm); zebrafish optional third arm leveraging the O5 imaging pipeline[58]
Detector (recommended)	DNA-damage markers γH2AX, 53BP1 foci, Rad52 — chosen for single-cell resolution, established kinetics, and cross-species comparability; membrane-lipid and protein-turnover arms as candidate classes 2 and 3
Design	Within-subject rate comparison across three conditions: active wake; quiet wake (EEG-verified); natural sleep — with damage load equalized at condition entry
Milieu clamp	Noradrenergic antagonist + adenosine-receptor agonist to mimic the sleep milieu in enforced quiet wake, with GRAB-sensor verification that the clamp actually reproduces the endogenous milieu; unclamped quiet-wake arm as internal control
Controls (7)	EEG/EMG state scoring; circadian-phase balancing; stress-marker panel (corticosterone); deprivation-method controls; detector-kinetics validation; blinded scoring; pre-registered analysis plan

Branching (pre-committed)	**Outcome A** (state advantage in ≥1 class): P1 supported; thesis strengthened. **Outcome B** (advantage only in clamped quiet wake): milieu, not state, carries the window — thesis narrows. **Outcome C** (no advantage anywhere, ≥2 of 3 candidate classes negative at design quality): **kill criterion D1 fires**; the window thesis is retracted as formulated. **Outcome D** (mixed): coverage-degree rule — the thesis survives only for the positive classes, in writing, with no expansion by framing.
Human minimal version	MRS metabolomics + CSF sampling across enforced quiet wake vs. sleep in clinical settings where lumbar drainage already exists (no new invasive burden)
Feasibility	All components exist in published form; the novel element is their combination under clamp and pre-registration, not any single technique

Two properties of F1 matter beyond its result. It is *symmetric*: every outcome, including the kill, is publishable and pre-committed. And it closes the design gap that makes P1 currently open: no existing study compares *rates* across EEG-verified quiet wake and sleep with the milieu controlled — the deprivation designs all confound state with stress[4,13].

6.2 E101: the operative near-term version

F1's full clamp design is a multi-year program. Its operative near-term version (register entry E101) strips the design to what a single well-equipped lab could run within one funding cycle: mouse only; γH2AX/53BP1 only; three conditions (active wake / quiet wake / sleep) with EEG verification and circadian balancing; corticosterone panel; no pharmacological clamp (the clamp arm drops out; the milieu question is deferred, not answered). E101 cannot deliver Outcomes B or C at full stringency — its pre-committed branching therefore reads: a positive state advantage upgrades P1 to "supported (single species, single class, unclamped)"; a null result does *not* fire D1 (insufficient coverage) but downgrades the thesis's confidence and prioritizes the clamped version. The asymmetry is deliberate: the cheap experiment may strengthen but may not kill.

6.3 E109: the ctenophore specification

E109 settles the hard void of Section 5.4 with three pre-committed stages, transferring the design that established cnidarian sleep[40] to the phylum where the confounder structure is different:

1. **Dark-phase infrared videography** of *Pleurobrachia* (or Mnemiopsis) across full 24-h cycles: does a reversible quiescent state exist at all outside the light phase, where the published claim concentrated[8]?
2. **Arousal-threshold measurement against a satiety control.** This stage exists because of the ambush-predator confounder: an arousal threshold separates sleep-like quiescence from sit-and-wait foraging, and the satiety manipulation separates hunting posture from state (a fed ambush predator that still "drifts" at threshold is in a state; one that stops drifting is hunting).
3. **Deprivation and rebound.** Mechanical/optogenetic deprivation of the candidate state, followed by rebound measurement — the homeostasis criterion that has defined sleep-like states from worm to jellyfish[40,42].

Branching is pre-committed: any stage's negative result stops the pipeline and records "no evidence for sleep-like state at stage *k*" — a result this cartography would cite as gladly as a positive one, since a demonstrated *absence* of sleep in a phylum with an independently evolved nervous system[39] would be the single most informative negative datum in the origin line.

7 Discussion

7.1 What would change the picture

The three lines of this paper have different futures. The **condition cartography** (Section 4) is stable: its answer form is bounded from both sides (lethality below, plasticity above), and its decision criterion G5 names the two observations that would reopen it — neither of which exists. The **origin cartography** (Section 5) is stable at Levels 1 and 3 (molecular antiquity is overdetermined; the first coupling is unobservable in principle) and improvable at Level 2: the O5 chain needs a second house, and the O2 chain needs a measured repair endpoint. The **window thesis** (Section 3) is the deliberately fragile

component: it stands on three supported and two open clauses, and its own kill criteria are executable. If F1 returns Outcome C, this paper's Section 3 should be cited as a retracted construction, and the two cartographies — which never leaned on the thesis — stand unaffected. That separability is by design, and we consider it the paper's central architectural property.

7.2 Honest contradictions and open watches

Four items are registered against us and remain unresolved. **(i)** Locus-coeruleus lesion does not abolish slow-wave homeostasis in rat[7] — against any simple arousal-off reading of the window. **(ii)** The fly's adenosine receptor is dispensable for sleep homeostasis[56] — against somnogen universality, and a reminder that P5 claims machinery, not molecules. **(iii)** The lethal-deprivation phenotype is confounded by method stress and bacterial invasion[4,13] — P4 stays open until a demonstrated stress-free deprivation design exists; D3 specifies the standard. **(iv)** Several single-study or preprint-level entries sit on *watch* status in the register (including the ctenophore preprint[8] and a small set of 2025–2026 reports awaiting replication[12]); the project's recheck duty is logged, not theatrical — items are re-examined at sensible intervals and the log says when and with what result.

7.3 Relationship to existing theories

The window thesis is not a competitor to the field's major frameworks so much as a claim about a different variable. The *synaptic homeostasis hypothesis*[53] addresses synaptic down-selection; the *glymphatic* framework[57] addresses clearance; energy-restoration and energy-allocation frameworks[3,47] address metabolic bookkeeping; metaregulation and recovery-function frameworks[30,55] address recovery scheduling; adaptive inactivity[49] addresses ecological timing. K13's distinctive claim is narrow: for the state-bound maintenance subset, the *rate* differs by state, and the homeostat is coupled to the damage counter. That claim is compatible with every framework above — and falsifiable independently of all of them (D1). Where frameworks disagree about sleep's *purpose*, the cartographies here suggest the disagreement is partly about question management: different theories answer different thirds of the problem (Section 1.1), and the function literature's habit of ranking them against each other may be ranking answers to different questions.

7.4 Limitations

Beyond the method limitations (Section 2.5), three content limitations deserve naming. **First**, the origin cartography's load-bearing chain is lineage-concentrated (FS08, Section 5.3); a replication of the zebrafish/cnidaria chain by an independent house would change the evidence weight more than any new argument could. **Second**, the window thesis's open clauses are open for design reasons, not data scarcity — P1 lacks a milieu-clamped rate comparison and P4 lacks a stress-free deprivation design; both are executable, and until executed the thesis is construction, full stop. **Third**, the ctenophore void means the strongest available version of the universality premise ("all animals sleep") is currently unproven at the phylum level[8,39]; every argument in this paper that leans on deep conservation is therefore, strictly, an argument about animals with nervous systems of the cnidarian-bilaterian type.

7.5 Outlook

The near-term empirical agenda is fully specified (Section 6): E101 is runnable now; F1 defines the decisive design; E109 defines the phylum-level test. The near-term theoretical agenda is a replication-and-independence program: second houses for the O5 chain, a measured repair endpoint for O2, and the first pharmacological-substitution study for the condition cartography's named gap. If these run, the question "why must sleep happen?" stops being a debate about intuitions and becomes, clause by clause, a set of measurements. This paper's bet is on the window; its commitment is to the criteria.

8 Conclusions

1. "Why must sleep happen?" is three questions. Separating them — function, condition, origin — is itself a result: several canonical disagreements dissolve into answers to different thirds of the problem.

2. The condition question is answerable now: sleep is *conditionally* essential — essential when the state-bound maintenance debt cannot otherwise be carried, liftable by rewiring, mobilization, and (nobody has tried) substitution. The enforced invariant is a clearing condition, not a dose.

3. The origin question is answerable at two of three levels: the machine is older than the animal (molecules, evidenced; coupling, partially evidenced; first coupling, unobservable in principle). The only fully measured damage→state→repair chain rests on one research house and awaits independent replication.

4. The function question has a falsifiable candidate — the window thesis — with three of five clauses supported, two open, and three pre-committed kill criteria. Its central open clause (rate advantage) is testable with existing technology, and the test (F1/E101) is specified to pre-registration depth, including the branching under which the thesis dies.

5. Methodologically, the project demonstrates that an explicit epistemic-safeguard and correction practice is executable in a single-author-plus-AI workflow — including a correction that ran against the project's own central discriminator. We offer that practice as a reusable instrument, and its instruments — register, safeguards, version protocol, correction ledger — for inspection on request.

Declarations

AI assistance. Literature search, evidence-register maintenance, drafting support, and figure generation were performed with the assistance of an AI system (Kimi, Moonshot AI). The AI system is not an author. All factual claims were verified against retrievable sources; all reference metadata were checked by direct lookup; all interpretive and correction decisions were made by the human author, who takes full responsibility for the content.

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Data availability. The curated evidence register (109 entries, 294 source records), the versioned answer-form documents, the experiment workshop specification (F1/E101), and the correction ledger are available from the author on request; a public deposit is planned with a subsequent journal-style version.

Peer-review status. This preprint has not been peer reviewed. Watch-status sources are flagged in-text; the ctenophore study cited (ref. 8) is an unreviewed preprint and is used only to establish a void, never as affirmative evidence.

Correspondence. Christian Evertz, Cologne, Germany — via the comment function of the preprint server.

References

1. Aguillon, N., Harduf, D., Sagi, D., Simon-Blecher, N., Levy, O., Oren, M., & Appelbaum, L. (2026). DNA damage modulates sleep drive in basal cnidarians with divergent chronotypes. *Nature Communications, 17*, 3.

2. Allada, R., & Siegel, J. M. (2008). Unearthing the phylogenetic roots of sleep. *Current Biology, 18*, R670–R679.

3. Benington, J. H., & Heller, H. C. (1995). Restoration of brain energy metabolism as the function of sleep. *Progress in Neurobiology, 45*, 347–360.

4. Bergmann, B. M., Gilliland, M. A., Feng, P. F., Russell, D. R., Shaw, P., Wright, M., Rechtschaffen, A., & Alverdy, J. C. (1996). Are physiological effects of sleep deprivation in the rat mediated by bacterial invasion? *Sleep, 19*, 554–562.

5. Blum, I. D., Zhu, L., Moquin, L., Kokoeva, M. V., Gratton, A., Giros, B., & Storch, K. F. (2014). A highly tunable dopaminergic oscillator generates ultradian rhythms of behavioral arousal. *eLife, 3*, e05105.

6. Chikahisa, S., Fujiki, N., Kitaoka, K., Shimizu, N., & Séi, H. (2009). Central AMPK contributes to sleep homeostasis in mice. *Neuropharmacology, 57*, 369–374.

7. Cirelli, C., Huber, R., Gopalakrishnan, A., Southard, T. L., & Tononi, G. (2004). Locus ceruleus control of slow-wave homeostasis. *Journal of Neuroscience, 24*, 3603–3611.

8. Courtney, R., Pickering, C., et al. (2020). Sleep-like behavior in the ctenophore *Pleurobrachia pileus* [preprint, not peer reviewed; metadata per project register]. *bioRxiv*.

9. DeBardeleben, H. K., Lopes, L. E., Nessel, M. P., & Raizen, D. M. (2017). Stress-induced sleep after exposure to ultraviolet light is promoted by p53 in *Caenorhabditis elegans*. *Genetics, 207*, 571–582.

10. Duboué, E. R., Keene, A. C., & Borowsky, R. L. (2011). Evolutionary convergence on sleep loss in cavefish populations. *Current Biology, 21*, 671–676.

11. Dworak, M., McCarley, R. W., Kim, T., Kalinchuk, A. V., & Basheer, R. (2010). Sleep and brain energy levels: ATP changes during sleep. *Journal of Neuroscience, 30*, 9007–9016.

12. Evertz, C. (2026). *Why must sleep happen? — Curated evidence register (inventory of state-bound processes, version 33) and companion working documents.*

Unpublished project documents; available from the author on request.

13. Everson, C. A., Bergmann, B. M., & Rechtschaffen, A. (1989). Sleep deprivation in the rat: III. Total sleep deprivation. *Sleep, 12*, 13–21.

14. Frank, M. G., Issa, N. P., & Stryker, M. P. (2001). Sleep enhances plasticity in the developing visual cortex. *Neuron, 30*, 275–287.

15. Funato, H., Miyoshi, C., Fujiyama, T., Kanda, T., Sato, M., Wang, Z., et al. (2016). Forward-genetics analysis of sleep in randomly mutagenized mice. *Nature, 539*, 378–383.

16. Gandhi, A. V., Mosser, E. A., Oikonomou, G., & Prober, D. A. (2015). Melatonin is required for the circadian regulation of sleep. *Neuron, 85*, 1193–1199.

17. Grubbs, J. J., Lopes, L. E., van der Linden, A. M., & Raizen, D. M. (2020). A salt-induced kinase is required for the metabolic regulation of sleep. *PLoS Biology, 18*, e3000220.

18. Hardie, D. G., Ross, F. A., & Hawley, S. A. (2012). AMPK: a nutrient and energy sensor that maintains energy homeostasis. *Nature Reviews Molecular Cell Biology, 13*, 251–262.

19. He, Y., Jones, C. R., Fujiki, N., Xu, Y., Guo, B., Holder, J. L., Jr., Rossner, M. J., Nishino, S., & Fu, Y. H. (2009). The transcriptional repressor DEC2 regulates sleep length in mammals. *Science, 325*, 866–870.

20. Hill, A. J., Mansfield, R., Lopez, J. M. N. G., Raizen, D. M., & Van Buskirk, C. (2014). Cellular stress induces a protective sleep-like state in *C. elegans*. *Current Biology, 24*, 2399–2405.

21. Huang, Z. L., Qu, W. M., Eguchi, N., Chen, J. F., Schwarzschild, M. A., Fredholm, B. B., Urade, Y., & Hayaishi, O. (2005). Adenosine A_{2A}, but not A_1, receptors mediate the arousal effect of caffeine. *Nature Neuroscience, 8*, 858–859.

22. Jez, J. M., & Penning, T. M. (2001). The aldo-keto reductase (AKR) superfamily: an update. *Chemico-Biological Interactions, 130–132*, 499–525.

23. Joiner, W. J. (2016). Unraveling the evolutionary determinants of sleep. *Current Biology, 26*, R1073–R1087.

24. Ju, Y. S., Ooms, S. J., Sutphen, C., Macauley, S. L., Zangrilli, M. A., Jerome, G., Fagan, A. M., Mignot, E., Zempel, J. M., Claassen, J. A. H. R., & Holtzman, D. M. (2017). Slow wave sleep disruption increases cerebrospinal fluid amyloid-β levels. *Brain, 140*, 2104–2111.

25. Kanaya, H. J., Park, S., Kim, J. H., Kusumi, J., Krenen, S., Sawai, E., et al. (2020). A sleep-like state in *Hydra* unravels conserved sleep mechanisms during the evolutionary development of the central nervous system. *Science Advances, 6*, eabb9415.

26. Kavanau, J. L. (1998). Vertebrates that never sleep: implications for sleep's basic function. *Brain Research Bulletin, 46*, 269–279.

27. Keene, A. C., & Duboué, E. R. (2018). The origins and evolution of sleep. *Journal of Experimental Biology, 221*, jeb159533.

28. Kempf, A., Song, S. M., Talbot, C. B., & Miesenböck, G. (2019). A potassium channel β-subunit couples mitochondrial electron transport to sleep. *Nature, 568*, 230–234.

29. Konietzka, J., Fritz, M., Spiri, S., McWhirter, R., Leha, A., Palumbos, S., et al. (2020). Epidermal growth factor signaling promotes sleep through a combined series and parallel neural circuit. *Current Biology, 30*.

30. Krueger, J. M., & Obál, F., Jr. (2003). Sleep function. *Frontiers in Bioscience, 8*, d511–d519.

31. Lesku, J. A. (2026). DNA repair as a core function of sleep. *Trends in Neurosciences*.

32. Lesku, J. A., Rattenborg, N. C., Valcu, M., Vyssotski, A. L., & Kempenaers, B. (2012). Adaptive sleep loss in polygynous pectoral sandpipers. *Science, 337*, 1654–1658.

33. Leung, L. C., Wang, G. X., & Mourrain, P. (2019). Neural signatures of sleep in zebrafish. *Nature, 571*, 198–204.

34. Liu, Z., Jiang, L., Li, C., Li, C., Yang, J., Yu, J., Mao, R., & Rao, Y. (2022). LKB1 is physiologically required for sleep from *Drosophila melanogaster* to *Mus musculus*. *Genetics, 221*, iyac082.

35. Lyamin, O. I., Manger, P. R., Ridgway, S. H., Mukhametov, L. M., & Siegel, J. M. (2008). Cetacean sleep: an unusual form of mammalian sleep. *Neuroscience & Biobehavioral Reviews, 32*, 1451–1484.

36. Manchester, L. C., Coto-Montes, A., Boga, J. A., Andersen, L. P. H., Zhou, Z., Galano, A., Vriend, J., Tan, D. X., & Reiter, R. J. (2015). Melatonin: an ancient molecule that makes oxygen metabolically tolerable. *Journal of Pineal Research, 59*, 403–419. https://doi.org/10.1111/jpi.12267

37. Mander, B. A., Rao, V., Lu, B., Saletin, J. M., Lindquist, J. R., Ancoli-Israel, S., Jagust, W., & Walker, M. P. (2013). Prefrontal atrophy, disrupted NREM slow waves and impaired hippocampal-dependent memory in aging. *Nature Neuroscience, 16*, 357–364.

38. Mignot, E. (2008). Why we sleep: the temporal organization of recovery. *PLoS Biology, 6*, e106.

39. Moroz, L. L., Kocot, K. M., Citarella, M. R., Dosung, S., Norekian, T. P., Povolotskaya, I. S., et al. (2014). The ctenophore genome and the evolutionary origins of neural systems. *Nature, 510*, 109–114.

40. Nath, R. D., Bedbrook, C. N., Abrams, M. J., Basinger, T., Bois, J. S., Prober, D. A., Sternberg, P. W., Gradinaru, V., & Goentoro, L. (2017). The jellyfish *Cassiopea* exhibits a sleep-like state. *Current Biology, 27*, 2984–2990.e3.

41. Porkka-Heiskanen, T., Strecker, R. E., Thakkar, M., Bjorkum, A. A., Greene, R. W., & McCarley, R. W. (1997). Adenosine: a mediator of the sleep-inducing effects of prolonged wakefulness. *Science, 276*, 1265–1268.

42. Raizen, D. M., Zimmerman, J. E., Maycock, M. H., Ta, U. D., You, Y. J., Sundaram, M. V., & Pack, A. I. (2008). Lethargus is a *Caenorhabditis elegans* sleep-like state. *Nature, 451*, 569–572.

43. Rattenborg, N. C., Voirin, B., Cruz, S. M., Tisdale, R., Dell'Omo, G., Lipp, H. P., Wikelski, M., & Vyssotski, A. L. (2016). Evidence that birds sleep in mid-flight. *Nature Communications, 7*, 12468.

44. Rechtschaffen, A. (1998). Current perspectives on the function of sleep. *Perspectives in Biology and Medicine, 41*, 359–390.

45. Rechtschaffen, A., & Bergmann, B. M. (1995). Sleep deprivation in the rat by the disk-over-water method. *Behavioural Brain Research, 69*, 55–63.

46. Roustan, V., Jain, A., Teige, M., Ebersberger, I., & Weckwerth, W. (2016). An evolutionary perspective of AMPK–TOR signaling in the three domains of life. *Journal of Experimental Botany, 67*, 3897–3907.

47. Schmidt, M. H. (2014). The energy allocation function of sleep: a unifying theory of sleep, torpor, and continuous wakefulness. *Neuroscience & Biobehavioral Reviews, 47*, 122–143.

48. Schnitzler, C. E., Pang, K., Powers, M. L., Reitzel, A. M., Ryan, J. F., Simmons, D., et al. (2012). Genomic organization, evolution, and expression of photoprotein and opsin genes in *Mnemiopsis leidyi*: a new view of ctenophore photocytes. *BMC Biology, 10*, 107.

49. Siegel, J. M. (2009). Sleep viewed as a state of adaptive inactivity. *Nature Reviews Neuroscience, 10*, 747–753.

50. Siegel, J. M. (2008). Do all animals sleep? *Trends in Neurosciences, 31*, 208–213.

51. Stenberg, D., Litonius, E., Halldner, L., Johansson, B., Fredholm, B. B., & Porkka-Heiskanen, T. (2003). Sleep and its homeostatic regulation in mice lacking the adenosine A_1 receptor. *Journal of Sleep Research, 12*, 283–290.

52. Tan, D. X., Hardeland, R., Manchester, L. C., Paredes, S. D., Korkmaz, A., Sainz, R. M., Mayo, J. C., Fuentes-Broto, L., & Reiter, R. J. (2010). The changing biological roles of melatonin during evolution: from an antioxidant to signals of darkness, sexual selection and fitness. *Biological Reviews, 85*, 607–623.

53. Tononi, G., & Cirelli, C. (2006). Sleep function and synaptic homeostasis. *Sleep Medicine Reviews, 10*, 49–62.

54. Vaccaro, A., Kaplan Dor, Y., Nambara, K., Pollina, E. A., Lin, C., Greenberg, M. E., & Rogulja, D. (2020). Sleep loss can cause death through accumulation of reactive oxygen species in the gut. *Cell, 181*, 1307–1328.

55. Vyazovskiy, V. V. (2015). Sleep, recovery, and metaregulation: explaining the benefits of sleep. *Nature and Science of Sleep, 7*, 171–184.

56. Wu, M. N., Ho, K., Crocker, A., Yue, Z., Koh, K., Sehgal, A., & Joiner, W. J. (2009). The effects of caffeine on sleep in *Drosophila* require PKA activity, but not the adenosine receptor. *Journal of Neuroscience, 29*, 11029–11037.

57. Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., & Nedergaard, M. (2013). Sleep drives metabolite clearance from the adult brain. *Science, 342*, 373–377.

58. Zada, D., Bronshtein, I., Lerer-Goldshtein, T., Garini, Y., & Appelbaum, L. (2019). Sleep increases chromosome dynamics to enable reduction of accumulating DNA damage in single neurons. *Nature Communications, 10*, 895.

59. Zada, D., Sela, Y., Matosevich, N., Monsonego, A., Lerer-Goldshtein, T., Nir, Y., & Appelbaum, L. (2021). Parp1 promotes sleep, which enhances DNA repair in neurons. *Molecular Cell, 81*, 4979–4993.e7.

60. Zepelin, H., & Rechtschaffen, A. (1974). Mammalian sleep, longevity, and energy metabolism. *Brain, Behavior and Evolution, 10*, 425–470.