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Temporal Dynamics of Herbal Effects in a Phase-Based Time Geometry

Multi-Scale Rhythms and Phase Dynamics in Biology

Biological systems operate on multiple rhythmic scales, from the fast beat of the heart and breath to daily and seasonal cycles. These *multi-scale rhythms* are often categorized as **ultradian** (shorter than 24 hours), **circadian** (~24 hours), and **infradian** (longer than 24 hours) [1]. For example, humans cycle through ultradian patterns like the 90-minute REM–NREM sleep cycle or pulsatile hormone releases within a day [1]. Circadian rhythms (~24h) regulate sleep-wake and hormone cycles, and infradian rhythms include monthly and annual (circannual) patterns such as menstrual cycles or seasonal affective changes [1]. Crucially, these rhythms are not isolated: they nest and interact across scales. A **hierarchy of oscillations** remains remarkably preserved across evolution, enabling *"multiple-time-scale communication within and across networks"* [2] – in other words, faster and slower cycles continuously coordinate.

Because of these interactions, *phase relationships* become important. Shorter cycles often align with phases of longer ones (**phase locking**). For instance, ultradian feeding and activity bouts in animals tend to occur at a specific phase of the daily circadian cycle when the master clock (SCN) is intact [3]. In voles, 2–6 hour ultradian activity episodes concentrate in the active (night) phase of the 24h rhythm (when the SCN is functioning), whereas without a circadian clock they spread randomly through the day [3]. Even on the scale of seconds, the body shows cross-scale phase coupling: heart rate speeds up during each inhale and slows on exhale (respiratory sinus arrhythmia), phase-locking the heartbeat to the breathing cycle [4]. These are examples of **cross-frequency coupling**, where a faster oscillation is modulated by the phase of a slower rhythm [5]. Such nested timing – e.g. high-frequency neural bursts occurring preferentially at a certain phase of a slow brain wave – is common and functionally significant [5]. In the brain, for instance, attention and memory involve theta waves (~5 Hz) coordinating with faster gamma bursts (~40 Hz) via phase synchronization [5] [6]. Overall, healthy physiology exhibits richly interwoven rhythms: fractal analyses show that variability at one timescale carries information about others, implying the body maintains a *"loose allegiance"* of oscillatory modes across scales [7]. This complexity means that an intervention at one scale (for example, a calming breath) can reverberate through slower scales, and vice versa, maintaining adaptability [8].

Phase-Locking and Entrainment Across Scales

Living systems also synchronize with environmental cycles. **Entrainment** is the process of locking an internal rhythm's phase to an external cycle (a Zeitgeber) [9]. The 24h light–dark cycle entrains the circadian clock (keeping our physiology aligned to day and night), and similarly, lunar and tidal cycles can entrain infradian rhythms. Notably, some species have distinct **circatidal** clocks: roughly 12.4-hour rhythms tuned to ocean tides [10]. These tidal rhythms persist even when the organism is isolated from daily light cues, implying a separate oscillator for the tide cycle [10]. In humans, evidence suggests a subtle **circalunar** (~29.5 day) influence on behavior – for example, sleep depth and hormones have been found to vary with moon phase under controlled conditions [11]. Thus, multiple oscillators in biology (daily, tidal, lunar, yearly)

interlock in a complex time-geometric dance. We can imagine each cycle as a circle of time; when two cycles interact, they form a torus-like structure in time (since mathematically a day-cycle and year-cycle together map to a torus topology S1×S1) [12]. The result is that an individual's internal state at any moment can be pinpointed by its phase in each relevant cycle (e.g. circadian phase, seasonal phase, etc.). Alignments or misalignments of these phases can produce constructive or disruptive interference in our physiology and mood. For example, if a fast ultradian cycle falls in sync with the peak of a circadian arousal cycle, one might experience a surge of energy or clarity; if they oppose each other, the person may feel "out of phase." Maintaining harmony among these rhythms is often associated with well-being [8].

Importantly, phase dynamics allow **real-time modulation**: by shifting the phase of one cycle, one can shift the composite state. This principle is exploited by practices like timed light exposure or meal timing to adjust circadian phase, and it underlies how certain herbs might exert their effects by nudging the timing of bodily clocks (**without making medical claims** here, we speak metaphorically). For instance, an herb taken at night that "slows the clock" could prolong the nocturnal restorative phase (much as evening bright light can phase-delay sleep), whereas a morning herb that "quickens the clock" might advance active-phase processes. In holistic traditions, daily and seasonal timing of remedies is often considered, implicitly acknowledging this phase-locking concept [10] [11].

Symbolic Time-Profile Taxonomy of Herbal Effects

We propose describing herbal effect profiles in terms of **rhythmic patterns** – symbolic time-geometries – rather than static outcomes. Each profile uses metaphorical language (pulse, tide, spiral, flare, drift) to characterize how an herb's influence unfolds over time. These profiles map onto parameters like onset speed, intensity oscillation, duration, and phase preferences, aligning with the multi-scale rhythms discussed. Below is a taxonomy of these time-profiles, including typical timescales and behaviors:

- **Pulse** – *Quick bursts.* A **pulse profile** is a short, pronounced effect that comes in bursts or rapid oscillations. This is analogous to a heartbeat or drumbeat: *staccato* and fast. **Parameters:** Very short cycle period or event (~seconds to minutes). Sharp onset and offset; high intensity but brief. May involve one or a few repeating spikes. **Behavior:** Pulsing herbs are like a jolt of energy or a sudden clarifying alertness. They act quickly and their influence is felt in discrete surges – for example, an herb that provides immediate stimulation or a rapid calming wave can be considered pulsing. **Visualization:** As a time-series, a pulse is a spiky waveform or a train of quick beats. On a phase chart, it might appear as tightly clustered blips. *Example metaphor:* think of a double espresso's effect, **without medical claim**, as a pulse – a quick heart-like thump of clarity that then subsides.

- **Flare** – *Sudden blaze followed by fading.* A **flare profile** rises rapidly to a peak like a flare of light and then gradually dissipates. **Parameters:** Onset is fast (minutes), peak intensity is high and brief, followed by an exponential decay over a relatively short duration (tens of minutes to a couple hours). Not strongly oscillatory or repeating – often a one-off peak per use (or a few minor aftershocks). **Behavior:** Flare herbs produce a clear, bright effect that **illuminates or energizes** quickly (hence "clear = flare"). They might sharpen the mind or mood in a flash, then gently taper off. Unlike a sustained rhythm, a flare is transient – akin to how cortisol surges upon waking (the cortisol morning surge is a natural "flare" that boosts alertness) or how a spicy aroma can cause an immediate, intense sensation that then melts away. **Visualization:** a steep spike that falls off gradually, like a firework fading. The flare might align with a particular time-of-day phase for maximum effect (e.g. a

morning herb that flares with the dawn cycle). In a toroidal plot, a flare could be marked as a bright spot moving along the daily cycle, short-lived but intense.

- **Tide** – *Gentle oscillation and ebb-flow.* A **tide profile** is a slow, sinusoidal rise and fall, evoking the ocean's tides (calm = tide). **Parameters:** Period is medium to long (multi-hour to ~12-hour half-cycle, often aligning with diurnal or semi-diurnal rhythms). Onset and offset are gradual; amplitude is moderate and steady. The effect waxes and wanes smoothly rather than spiking. **Behavior:** Tidal herbs have a **soothing, rhythmic influence** that washes in and out. They may promote calm or balance, with an effect that builds gently, plateaus, and recedes in a regular cycle. One might feel a subtle wave of tranquility or clarity that comes and goes over hours, analogous to how tidal water slowly advances and retreats. These could be herbs that synchronize with the body's inherent slow oscillations – for example, reinforcing the *rest-activity curve* around afternoon and early night. Indeed, some physiological rhythms are roughly 12 hours (half-day), reminiscent of tides [10], so an herb with a tide profile might align with such semi-diurnal cycles (perhaps a calming herb peaking in late evening and diminishing by morning). **Visualization:** a smooth wave on the time plot, repeating every half day or so. On the torus, it would appear as a band of gentle undulation along the daily loop. The parameters here include wave period (e.g. 8–12 hours), amplitude (depth of calm), and phase (timing of the high tide effect – maybe high tide at night for a sedating herb, low tide in day).

- **Spiral** – *Progressive cyclical change (helix).* A **spiral profile** is an oscillation that either intensifies or transforms with each cycle – imagine a spiral staircase, each loop either ascending or descending. **Parameters:** Multi-cycle pattern: a moderate oscillation (period of minutes to hours) coupled with a slow modulation that changes its amplitude or center over a longer term. It essentially has two timescales: a shorter repeating cycle and a longer drift superimposed. This produces a helix-like trajectory if plotted in phase space. **Behavior:** Spiral herbs lead one through **layers of experience** – each successive wave of effect builds on the previous, either deepening or shifting in quality. For example, a "dream" herb may initially relax the body (first loop), then gradually engage deeper imaginative or subconscious activity with each succeeding cycle of influence (subsequent loops), akin to *spiraling into a dream state*. The feeling might be cyclic (like waves of drowsiness or vision) but with a trend – either intensifying (getting dreamier or more introspective with time) or decaying (starting vivid then gently bringing one back). The term *spiral* also implies a coupling of short and long rhythms – much like how ultradian REM cycles occur multiple times and evolve across the night. **Visualization:** a spiral in time: if one axis is the short cycle phase and another the slow change, the effect trace makes a spiral curve. For instance, each breath or heartbeat might feel slower and deeper than the last under a spiral-calming herb, or each 30-minute loop of mental clarity might become progressively more pronounced before tapering. On a toroidal view, a spiral might appear as a path that doesn't retrace the same circle but moves poloidally and toroidally simultaneously (like a helical band around the torus). Key parameters are the base cycle length, the rate of amplitude change per cycle, and the direction of change (upward spiral vs downward spiral).

- **Drift** – *Slow drift or shift of baseline.* A **drift profile** is characterized by a monotonic or wandering change over long time frames with minimal pronounced oscillation. It's a *gradual tide that never quite reverses* within the observation window – more like a current than a wave. **Parameters:** Very long effective period (could be many hours to days), often approaching a one-directional trend within the relevant timeframe. Amplitude change is slow and subtle. **Behavior:** Drift herbs gently **nudge the overall state** in a direction without abrupt phases. For example, an adaptogenic herb might slowly build vitality or resilience over weeks – each dose doesn't cause a noticeable immediate cycle, but

over time one's baseline "drifts" upward. Or conversely, a nightly sedative could cause a slow drift toward sleepiness that accumulates and then recovers after sleep. The effect is more like a steady glide or a shift in the center of gravity of one's energy. Drifts can also represent *long-cycle modulations*, such as seasonal attunement – e.g., an herb that gradually adjusts you to winter, producing a seasonal drift in mood or metabolism. **Visualization:** as a nearly straight or gently curving line over time, lacking pronounced peaks. On a torus, a drift might show up as a slight offset or tilt of the normal daily cycle – for instance, the whole daily rhythm might run a bit "cooler" or "warmer" under the herb's influence, shifting the baseline of the sinusoids. Key parameters include drift rate (slope of change) and duration (how long the drift continues before leveling off).

Each herbal effect can be seen as a combination of these fundamental profile types. For instance, a complex herb might have a *pulse-spike* at the beginning (immediate alertness), followed by a *tide-like* sustained calm, and then a slow *drift* upward in overall mood later. By describing profiles in this way, we avoid direct medical claims and instead use **metaphors of rhythms and behaviors** (e.g. "soothing wave" vs. "sedative") to characterize outcomes. This taxonomy provides a common language to compare how different herbs "feel" over time – does it come on like a lightning flash or a rolling wave? Does it repeat in cycles or guide you deeper in a spiral? These rhythmic metaphors map more intuitively to human experience than clinical terms, and they also hint at underlying physiological entrainment (a "tide" herb perhaps working with your circadian relaxation phase, a "pulse" herb tapping a fight-or-flight burst, etc.).

Parameter ranges summary: In simplified terms, *Pulse* ~ period of seconds–minutes (ultrafast), *Flare* ~ rapid onset peaking within <1 hour then decaying, *Tide* ~ semi-diurnal or hours-long cycles, *Spiral* ~ medium cycles (minutes–hours) with long-term modulation, *Drift* ~ effectively one-cycle-per many hours or a one-way change (very low frequency). Amplitudes and onset/offset slopes vary: pulse and flare have high amplitude and steep slopes; tide has moderate amplitude, sinusoidal slope; spiral has evolving amplitude per cycle; drift has low amplitude per unit time but accumulative change. These profiles can be quantified in a future framework by metrics like *period (τ)*, *duty cycle*, *peak delay*, *decay constant*, *phase angle relative to circadian*, etc., but for our purposes, the qualitative ranges suffice to distinguish them.

Visualization in a Toroidal Time-Geometry

To map these profiles into a **shared temporal field**, we employ a *toroidal/poloidal phase space*. In this visualization, time is represented as cyclical dimensions. Imagine a torus (donut shape) where the **toroidal** direction (the big loop around the hole) corresponds to a long cycle like the yearly seasonal rhythm, and the **poloidal** direction (the small loop through the donut's tube) corresponds to a shorter cycle like the 24-hour day. Every point on the torus can be identified by two angles: one for the season phase and one for the time-of-day phase [12]. This provides a 2D phase coordinate (like "November and 8:00am" might be one point, and "June and 8:00am" a different point one full turn around the torus). Such a *modular timespace* lets us plot complex rhythms intuitively [13]. Daily, weekly, monthly, and yearly cycles become interlocking circles in this framework [13]. For example, if we also included a weekly cycle, that would add another "loop" – but to keep it simple, we focus on daily vs. seasonal, with an optional lunar overlay.

Short vs Long Cycles: Using toroidal geometry, we can visualize short-cycle effects (like the pulse or tide within a day) in conjunction with long-cycle effects (like seasonal drift or circannual timing) on one coherent map. The **poloidal (small radius) loop** might be a 24-hour day: as you go around that loop, you move through morning, afternoon, evening, night. The **toroidal (major radius) loop** might represent a full year: one complete trip around the donut corresponds to spring→summer→fall→winter. Thus, as time advances,

a point representing “now” will spiral around the torus – it loops around many poloidal cycles (days) while gradually progressing toroidally through the seasons. This effectively creates a helical path where, say, each day is a ring on the tube and after 365 loops you return to the same spot on the torus (a year later). If we include the **lunar phase** (~29.5 days) as an overlay, we don’t add another permanent dimension (to avoid a 3-torus), but instead could encode it visually – e.g. coloring the torus or the path by lunar phase, or adding a subtle wobble to the daily loop that cycles every ~30 days. (For instance, the torus could “breathe” in and out slightly to indicate the waxing and waning moon, or simply mark full moons along the year loop).

Herbal Profiles on the Torus: Now, how do our herb rhythm profiles map onto this? Each herb’s effect can be visualized as a pattern on the torus surface or within the toroidal volume, spanning the short and long cycles it engages. A **pulse** effect might show up as a small localized hotspot on a particular day’s segment of the torus – bright but confined (since it’s short-lived relative to the day, it might appear as a blip along the daily ring, repeated maybe only once or a few times). A **tide** effect, which oscillates over hours, could be drawn as a wave-like band around the torus: for example, a calming tide that peaks at night would appear as a sinuous band that has high values on the night side of each daily loop and low on the day side, smoothly repeating for each rotation around the torus. This essentially overlays a 24h sinusoid onto the torus, possibly shifting slowly with seasons if the effect changes in different seasons. A **spiral** effect might appear as a spiral path on the torus itself: imagine an herb that over several days leads you into deeper relaxation cycles – its representation could be a line that starts at one phase on day 1 and with each day’s loop drifts in phase or amplitude, circling into the interior or exterior of the torus tube, tracing a helical groove. **Flare** effects might be rendered as starburst-like marks at certain coordinates: e.g. a morning flare herb could be a bright spot that appears on the morning section of each daily loop where the herb is active, then quickly fades (a localized spark on each loop). **Drift** effects would manifest as gradual shifts in the baseline: visually, perhaps the entire torus or the centerline of the daily cycle tilts or shifts over the year when the herb is taken. For instance, if an herb causes a winter drift toward higher energy, one might draw the winter segment of the torus slightly “elevated” in the energy dimension compared to baseline.

Interactive Time-Scrubbing: This toroidal model supports interactive exploration. A user could “scrub” through time by moving a pointer along the torus (either advancing continuous time or jumping to specific phase coordinates). As the pointer moves, one would see the state of each herb’s effect at that time. For example, if you scrub to 10 PM in mid-summer, the pointer highlights that location on the torus; an herb with a calm tide profile might show a high intensity at that point (since night is its peak), whereas an energizing pulse herb might show nothing (if it’s only effective in the morning when taken). This can be done in real-time, with the model updating the combined effect of multiple herbs or comparing an individual’s biorhythm with the herb overlay. **Real-time overlays** could allow stacking profiles: you could overlay your personal sleep-wake cycle (a circadian sinuous band on the torus) with a herb’s effect band to see how they interact. If they align (e.g. herb’s calming tide coincides with your natural dip at 3 PM), that might indicate a synergistic timing; if they clash (e.g. a stimulating pulse hitting during your usual wind-down phase), the visualization makes that conflict obvious. The toroidal view inherently handles these overlaps because each cycle is an axis – aligning along the torus means synchrony, while misalignment is visually apparent as a shift around the loop.

The **poloidal vs toroidal separation** helps delineate short-term vs long-term effects. Short-cycle effects (like pulses, tides) map around the poloidal direction (within one daily loop), while long-cycle modulation (like seasonal drift or monthly patterns) map along the toroidal direction (slow progression as you go around the year). We can thus literally see short and long effects in one glance: e.g., a spiral which involves change each day will show as a path that moves poloidally and toroidally – you might see it cutting

diagonally across the grid of day-vs-year. Meanwhile, a pure drift seasonal herb might simply show as a color gradient along the toroidal ring, indicating increasing effect toward winter.

Because the torus can be difficult to draw on paper, sometimes it's conceptually "unrolled" – e.g., one can imagine a cylindrical coordinate plot, or using an interactive sphere display as done in some data visualizations [13]. In fact, prior work has mapped human activity cycles onto spherical displays by projecting a torus onto a sphere [14] [15]. The idea is that *"human and environmental time has a rich internal structure… Representing time as a set of interlocking cycles can reveal patterns not apparent in a linear layout"* [13]. Our approach follows this principle. By factoring time into meaningful cycles and placing herb effects in that multi-dimensional time, we make it easier to see **temporal patterns**. For instance, an interactive tool could allow toggling the lunar overlay: if turned on, the torus (or sphere) might slightly distort or add a marker every 29.5 days. One might notice an herb's dream spiral tends to amplify around the full moon phase – a pattern that would be hard to spot on a flat timeline but could emerge on the toroidal map.

In summary, visualizing herbal effects in a toroidal phase space enables a **taxonomy-to-geometry link**: the qualitative rhythm profiles (pulse, flare, tide, spiral, drift) become visual patterns (spikes, bursts, waves, helices, gradients) anchored to biologically meaningful timelines (day, month, year). This not only provides an intuitive, metaphor-rich description for users (e.g. "This herb adds a gentle night-time wave to your annual cycle, like a calming tide each evening") but also lays the groundwork for interactive tools. Users could scrub through a 4D clock (time of day vs time of year) and see in real-time how an herb's influence grows or fades, or overlay multiple herbs to observe potential resonance or interference in their rhythms. Such a system invites a person to engage with their well-being in terms of **rhythmic balance** and phase alignment, rather than just doses and effects. It aligns with the idea that *tempo and timing* are as crucial as the ingredients themselves in understanding herbal and behavioral medicine, weaving the user into the fabric of natural cycles in a tangible way.

References (Key Sources on Oscillations, Rhythms, and Phase)

1. Butler et al. (2013) – *Fractal physiology and multiscale dynamics*: Demonstrates how the circadian clock influences multi-timescale patterns (e.g. heart rate fluctuations) and discusses cross-frequency coupling in physiological signals [5] [7].
2. Goh et al. (2019) – *Ultradian Rhythms Review*: Defines ultradian (shorter-than-daily) events and reports how ultradian cycles can phase-lock to circadian rhythms in animals (e.g. vole feeding bouts tied to active phase) [3].
3. SciDirect Topic "Biological Rhythm" (2024) – Summarizes types of rhythms: ultradian (<24h), circadian (~24h), infradian (>24h), with examples (hormone pulses, REM sleep, menstrual and seasonal cycles) [1]. Good for basic definitions and the concept of entrainment to environmental cues [9].
4. Ben-Tal et al. (2012) – *Respiratory Sinus Arrhythmia (RSA) study*: Explains the coupling of heart and breath (heart rate increasing on inhale, decreasing on exhale), an example of fast cycle modulated by a slower rhythm [4]. Illustrates micro-scale phase-locking in physiology.
5. Emery & Gachon (2025) – *Review of 12-hour (circasemidian) rhythms*: Discusses evidence for 12.4-hour **circatidal** rhythms in mammals and links to ancient tidal cycles [10]. Supports the "tide" concept and shows separate oscillators can exist beyond circadian.
6. Cajochen et al. (2013) – *Lunar cycle and sleep study*: Provides evidence of a ~29.5-day **circalunar** effect on human sleep (e.g. sleep quality dips around the full moon) [11]. Relevant for including lunar phase as an overlay in our time-geometry.

7. Kostakos et al. (2016) – *Torus visualization of cyclical data*: Describes mapping daily and weekly cycles onto a torus and then to an interactive sphere, noting that *interlocking cycles reveal patterns invisible in linear time* [13] [12]. Informs our toroidal design for showing multi-scale herb rhythms.
8. Buzsáki et al. (2013) – *Brain rhythms scaling*: Notes that a hierarchy of brain oscillations from slow to fast stays consistent across species, enabling communication across timescales [2]. Conceptually underpins how different rhythmic scales (like herb-induced cycles and innate cycles) can interact coherently.
9. West (2024) – *Complexity synchronization in physiology*: Argues that fractal (multi-scale) time series in heart, brain, lungs exhibit hidden synchronization, implying that alignment of complex rhythms yields better communication [8]. Supports the benefit of phase aligning herb effects with the body's rhythms.
10. Sauseng et al. (2008) – *Cross-frequency phase synchronization in the brain*: Demonstrates that theta and gamma brain waves sync in phase during attention and memory tasks [6]. This exemplifies how a slower "carrier" rhythm can coordinate faster activity – analogous to how an herb with a spiral profile might synchronize a user's fast and slow physiological responses for a unified effect.

Each of these references underlies our approach of treating herb effects as rhythmic phenomena: from basic definitions of rhythms to examples of cross-scale coupling and novel ways to visualize cycles. By integrating these insights, we bridge scientific understanding of oscillatory dynamics with a practical, metaphor-driven framework for herbal time profiles, aiming for an approach that is both **comprehensive and intuitively graspable**.

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