**Towards Cosmic Standard Time (CST):  
A Unified, Continuously‑Corrected Time for Inch‑Scale Positioning and Global Sensor Fusion**

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# Abstract

Positioning and navigation systems—from satellites to aircraft to phones—ultimately ride on time. Every meter of range in radio-based navigation is the product of a timestamp multiplied by the speed of light. Today, the world operates with multiple time scales (UTC with leap seconds, GPS Time without them, GLONASS/Galileo/BeiDou system times) and mixes local civil time zones for human display. These mismatches force conversions and introduce edge-case errors, while Earth’s rotation is slowly changing (length-of-day drift), requiring periodic corrections that can be awkward to handle uniformly.  
  
We propose Cosmic Standard Time (CST): a single, leap-second-free, continuously steered epoch that (i) keeps relativistic and Earth-rotation corrections explicit in metadata, (ii) publishes a smooth, real-time estimate of UT1−CST to account for Earth’s gradual slowing, and (iii) standardizes uncertainty reporting. CST does not make signals “faster than light”; instead, it reduces timing ambiguity so that timestamp errors fall well below 1 ns, enabling inch-scale (~2–3 cm) ranging when combined with modern antennas, multipath mitigation, and robust clocks. This paper outlines architecture, mathematical sensitivity, domain benefits, and a safe validation plan.

# 1. Motivation

Time is the coordinate of coordinates. All GNSS positioning solves for receiver clock error along with spatial coordinates. A cleaner, universal epoch reduces solver burden and error propagation.  
  
Inch-level goals demand picoseconds. Light travels ≈0.30 m per ns, so 1 ns timing error corresponds to ≈30 cm range error. Inch-class positioning requires ≤100 ps effective timing uncertainty plus good geometry and multipath control.  
  
Operational simplicity: multiple time scales and leap-second steps create conversion issues. A single epoch with smooth steering (no steps) eliminates a class of bugs when systems move between countries and datums.

# 2. Definition: What CST Is (and Isn’t)

CST definition (proposal):  
- A single, monotonic time scale with SI-second rate, no leap seconds.  
- Continuously steered to stay close to UT1 (Earth rotation) but without discrete steps.  
- Publishes live correction streams: (UT1−CST), (UTC−CST), relativistic coefficients, and per-system offsets (GPS, Galileo, BeiDou).  
- Every observation carries CST timestamp + uncertainty and a mapping vector to other scales.  
  
CST is not a faster-than-light mechanism. It does not speed signals; it removes timing inconsistency so range estimates are cleaner and sensor fusion more accurate. Civil-time zones remain for display only.

# 3. Architecture Overview

Clock Tiering:  
1. Primary Ensemble: multi-lab atomic ensembles produce CST with steering filters that minimize divergence from UT1 over long horizons without steps.  
2. Secondary Clocks: GNSS-disciplined oscillators (rubidium/OCXO) track CST when links are healthy; enter holdover with drift telemetry when not.  
3. Edge Nodes: sensors, vehicles, and applications carry CST with uncertainty and offsets to GPS/UTC/UT1 on every packet.  
  
Distribution & Metadata: authenticated broadcast of {CST epoch, UTC−CST, UT1−CST, per-system offsets, iono/tropo models, relativistic corrections, covariance}. Receivers maintain a timing state vector: clock bias/drift, link latency, and quality flags.  
  
Frames & Ephemerides: positions referenced to WGS‑84/ITRF with epoch tags; CST provides a single “when” for transforming between Earth-fixed and inertial frames and for applying Sagnac/relativistic terms consistently.

# 4. Key Mathematics (Conceptual)

Pseudorange sensitivity to time:  
 δρ ≈ c · δt  
where c ≈ 299,792,458 m/s. For δt = 1 ns → δρ ≈ 0.30 m (≈11.8 in). Goal: δt ≤ 100 ps to push range error below ~3 cm.  
  
Clock model (receiver):  
 t\_rx(CST) = t\_true + b + d·Δt + ε\_t  
with bias b, drift d, and noise ε\_t. CST reduces bias ambiguity by making scale/offset explicit and smooth.  
  
Earth rotation & Sagnac: apply Sagnac‑like correction using CST-consistent Earth-rate and geometry. Publishing (UT1−CST) continuously prevents step errors when Earth rotation models update.  
  
Relativistic adjustments: satellite clocks and high-speed platforms require gravitational and kinematic terms. CST distributes standardized coefficients to minimize vendor discrepancies.

# 5. Mechanisms: Why CST Improves Precision

1. No leap-second steps → no edge-case time jumps.  
2. Global epoch everywhere → no per-country recalibration.  
3. Uncertainty becomes first-class data, letting fusion engines weight observations appropriately.  
4. Consistent Earth-rotation treatment via continuous UT1 tracking.  
5. Cleaner multi-GNSS fusion via published offsets to system times.  
6. Deterministic replay and audit using saved CST correction streams.

# 6. Domain Benefits (Non-Operational)

Satellites / GNSS:  
- Sub-nanosecond timing alignment across constellations → tighter dilution of precision and faster convergence to cm-class solutions.  
- Reduced cross-system offset handling via CST offset streams.  
  
Civil Aviation & Spacecraft:  
- Common epoch for ADS‑B‑Next, satcom, and sensor timestamps → fewer fusion discrepancies in flight data and autonomy stacks.  
- Deep-space probes use CST for Earth‑probe light‑time solutions and clock correlation; ground networks ingest fewer conversion steps.  
  
Automotive, Robotics, UAS:  
- City-scale centimeter mapping with CST + RTK/PPP corrections + multipath mitigation → stable lane‑level localization.  
- Swarm synchronization with identical epoch reduces inter-robot drift.  
  
Telecom & Power Grids:  
- Phasor measurement units and 5G/6G time-sensitive networking gain sub-µs coherence; grid protection and scheduling improve.  
  
Earth Science:  
- VLBI, InSAR, and GNSS geodesy benefit from uniform epoching and smoother UT1 tracking, improving millimeter-per-year tectonic estimates.

# 7. Handling Earth’s Slowdown (Length-of-Day Drift)

Earth’s rotation is not constant; UT1 drifts relative to uniform atomic time. Instead of inserting leap seconds, CST publishes a continuous UT1−CST estimate and rate so systems can:  
- Tag measurements with the exact rotational phase at that instant.  
- Apply transforms between Earth‑fixed and inertial frames smoothly.  
- Avoid step changes that break logs, filters, and ring buffers.  
  
This achieves automatic compensation for the planet’s evolving rotation—quietly, continuously, and globally.

# 8. Practical Requirements to Reach Inch-Scale

- Time transfer: fiber-based PTP grandmasters, advanced GNSS common‑view, or optical links to push network timing jitter into the tens of ps regime.  
- Clocks: low-drift oscillators (OCXO/Rb) with holdover characterization and on-packet uncertainty.  
- Antennas & signal processing: multipath suppression, wideband codes, carrier-phase tracking, and ambiguity resolution.  
- Models: up-to-date troposphere/ionosphere and relativistic terms, distributed with CST.  
- Software discipline: carry CST + uncertainty end-to-end; avoid internal down-conversion to civil time.

# 9. Safety, Governance, and Interoperability

Publish CST as an open, civilian standard with academic and standards-body oversight. Provide conversion libraries (CST↔UTC↔GPS) and reference datasets. Ensure resilience via multiple independent primary ensembles, cryptographic authentication for correction streams, and graceful degradation to holdover.

# 10. Validation Plan (Safe & Reproducible)

1. Bench timing: compare CST transfer vs. UTC/GPS across labs; target <100 ps TDEV at 1–10 s.  
2. Simulated navigation: inject identical satellite geometries but vary time scales; show pseudorange residuals and solution scatter reduce under CST.  
3. Multi-GNSS fusion test: measure time-to-cm convergence and cycle-slip recovery with/without CST offset streams.  
4. Earth-rotation stress test: replay historical UT1 variability; verify transforms remain smooth and solutions stable (no leap-step artifacts).  
  
These steps are safe, reproducible, and appropriate for academic and civilian testbeds.

# Conclusion

CST is a single, smooth, uncertainty-aware epoch that everyone can use. Leap-free and continuously corrected for Earth’s slowing, explicit about offsets and relativistic terms, and precise enough for picosecond-class synchronization, CST enables inch-scale positioning and clean global sensor fusion without per-country recalibration. With CST, many engineering challenges become routine across satellites, aircraft, probes, and ground systems.  
  
References and appendices can be added on request, along with figures (timing stack diagram, error-to-distance chart) and an executive summary for decision-makers.