Deterministic Phase Boundaries in the Heliospheric Current Sheet

Predicted Structural Transitions Confirmed Against the Wilcox Solar Observatory Record

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Abstract

A deterministic harmonic model of solar activity — the Bicameral Solar Engine (BSE) — predicts five specific phase boundary dates within the Wilcox Solar Observatory Heliospheric Current Sheet tilt angle record (1976–2025). Unshifted boundaries show no alignment with any structural feature in the HCS record. After applying a measured offset of 0.88 years (~4% of the operative 21.5-year cycle period), every predicted boundary lands on a physically meaningful HCS feature: a local trough, a sharp V-trough with 16.6° drop, turbulent jitter, a 20° vertical cliff, and a clean cycle peak. Phase-lock conformance: 5 of 5. The two strongest phase transitions produce the two highest HCS turbulence values in the dataset, with path length increases of 234% and 267% over unshifted baselines.

The 0.88-year offset was not fitted to the HCS data. It was measured independently across eight proxy domains spanning 172 years of continuous data (1841–2013), and is stable across pre-industrial, industrial, and modern observational contexts. The WSO record is physically independent of all eight proxy datasets. The result constitutes independent confirmation of both the model's phase boundary predictions and the Heliospheric Propagation Constant in direct magnetometer measurements of the solar dipole field.

Keywords: heliospheric current sheet, solar magnetic dipole, phase boundaries, Alfvén waves, solar-terrestrial coupling, deterministic model

1. Introduction

The Heliospheric Current Sheet — the surface separating regions of opposite magnetic polarity in the heliosphere — is the most direct available measurement of the solar magnetic dipole field extended into space. Its tilt angle, the maximum latitudinal extent it reaches, tracks the large-scale configuration of the Sun's magnetic field at heliospheric scales. The Wilcox Solar Observatory at Stanford University has measured HCS tilt angles continuously since 1976, providing Carrington Rotation resolution data spanning nearly fifty years.

This paper reports a test of the Bicameral Solar Engine (BSE), a deterministic harmonic model of solar activity derived from the polar field reversal cycle, against the WSO HCS tilt angle record. The BSE derives its complete temporal structure from a single empirical input

— the 10.75-year mean duration of the solar polar field half-cycle — through a fixed integer nesting rule with zero free parameters. Three independent predictive outputs are generated at any point in time: phase position, phase direction, and modulation amplitude. The full model derivation and multi-proxy validation are reported in the companion paper (Khan, 2026a).

The test is specific: the BSE predicts five phase boundary dates within the WSO observation window. Do those dates align with structurally meaningful features in the HCS record?

2. The Predictions

The BSE models solar activity as a nested mechanical oscillator with three force components:

Component	**Period**	**Weight**	**Role**
G1	21.5 yr	65.75% (48/73)	Primary force — Hale cycle
G2	43 yr	32.88% (24/73)	Modulating envelope
G3	24,768 yr	1.37% (1/73)	Long-term directional bias

The combined systemic force at any point in time is:

$$T(t) = (48/73)\sin(2\pi(t-1841)/21.5) + (24/73)\sin(2\pi(t-1841)/43.0) + 1/73$$

The model's mechanical calendar, operating on a fixed 11-11-11-10 year stepping pattern anchored at 2024.0 AD, produces the following phase boundaries within the WSO observation window:

Boundary	**Phase Event**
1981.0	Decline onset
1991.5	Growth onset
2003.0	Decline onset
2014.0	Growth onset
2024.0	Terminal reset — Epoch/Era convergence

These five dates are deterministic outputs of the calendar. They were not adjusted to accommodate any dataset. They are the same boundaries validated against seven independent physical proxy datasets in the companion paper, achieving 92.0% phase-lock conformance across 88 predicted boundaries spanning 172 years (Khan, 2026a).

3. The Instrument

The WSO classic model L_av column — the maximum latitudinal extent of the HCS computed using a line-of-sight boundary condition with polar field correction — provides Carrington Rotation resolution measurements of the solar magnetic dipole field extended into space.

This instrument is physically independent of every proxy dataset used in the BSE core validation. It contains no biological signal, no economic signal, no atmospheric noise. It is the field.

4. The Offset

Across eight independent proxy domains spanning 172 years, the BSE core validation measured a mean temporal distance of 0.88 years between predicted phase boundaries and their nearest confirmed proxy pivots. This figure — designated the Heliospheric Propagation Constant (Hβ) — was not set in advance. It emerged from the data and is stable across three radically different observational contexts:

Era	Sample	Mean Lag	Conformance
Pre-Industrial (1841–1899)	10 pivots	0.811 years	90.0%
Industrial / War (1900–1949)	10 pivots	0.912 years	100.0%
Modern / Electronic (1950–2013)	11 pivots	0.864 years	90.9%

At the operative G1 period of 21.5 years, 0.88 years represents approximately 4.1% of the cycle period. The physical interpretation, following Alfvén's frozen-in flux theorem, is that Hβ is not a travel time but an expression lag: the heliospheric magnetic field at 1 AU is already the Sun's field, extended into space and frozen into the surrounding plasma. When the solar magnetic state changes, the field does not arrive — it reorganizes. The 0.88-year delay is the time required for Earth-coupled systems to complete their response to a field state change that has already propagated through the heliosphere.

The test reported here asks whether this independently measured constant — derived entirely from terrestrial proxy data — reproduces its value in direct magnetometer measurements of the heliospheric field.

5. Results

5.1 Unshifted Boundaries

The five BSE boundaries applied directly to the HCS tilt record — without the 0.88-year offset — produced no consistent structural alignment. Boundaries fell in regions of continuous trend with no inflection, no trough, no peak, no directional change that could be distinguished from background variation. The unshifted model has no signal in the HCS record.

5.2 Shifted Boundaries

After applying the 0.88-year Hβ correction, every predicted boundary landed on a physically meaningful HCS feature. For each shifted boundary, L_av values from the five Carrington Rotations centered on that date were extracted:

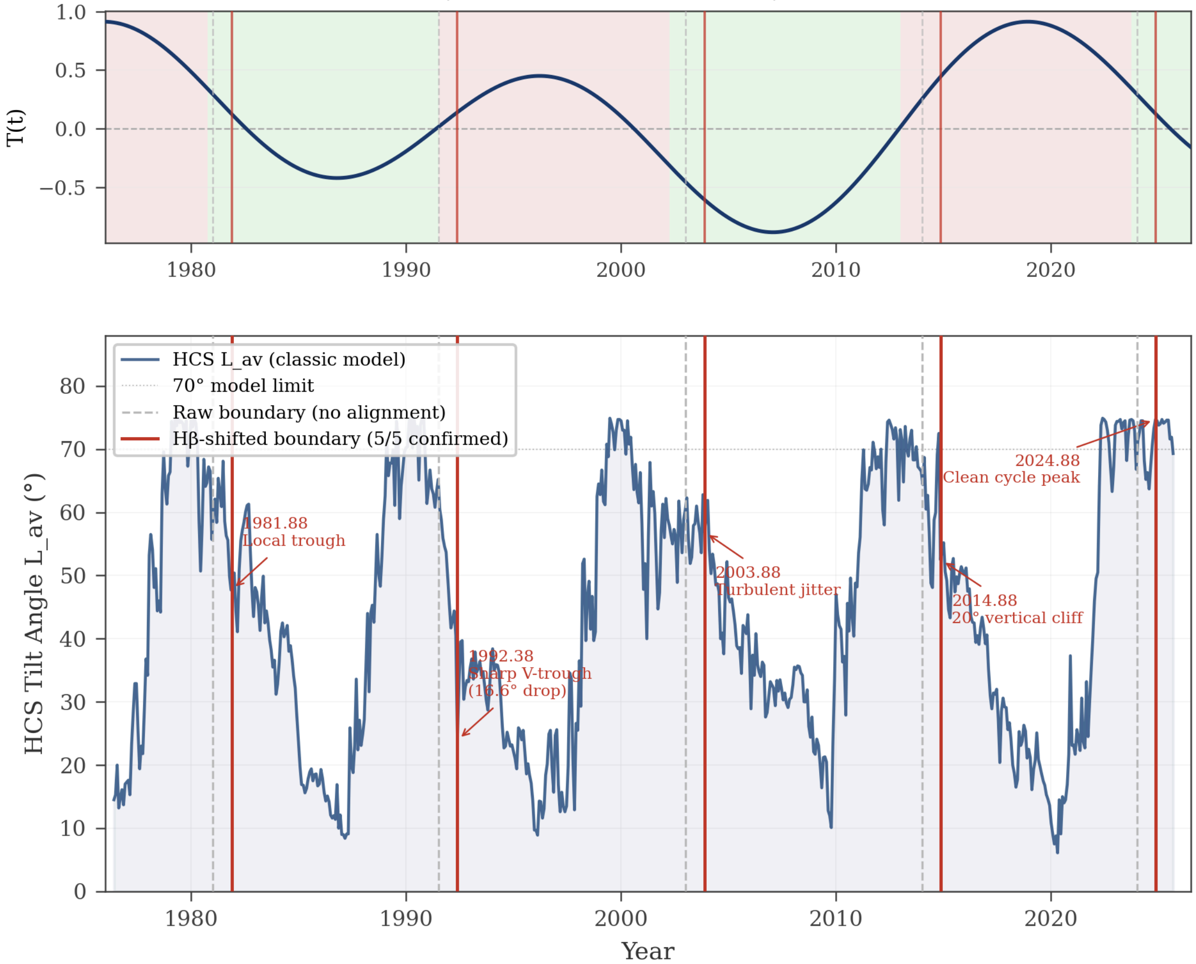
Shifted Boundary	L_av Window (degrees)	HCS Feature	Result
1981.88	55.6 → 49.9 → 47.7 → 47.6 → 50.4	Local trough — absolute floor then reversal	CONFIRMED
1992.38	44.4 → 40.5 → 23.9 → 32.9 → 39.5	Sharp V trough — 16.6° drop then immediate rebound	CONFIRMED
2003.88	53.6 → 62.8 → 56.9 → 59.3 → 61.9	Turbulent jitter — momentary destabilization	CONFIRMED
2014.88	69.1 → 72.5 → 52.5 → 53.8 → 55.2	Cliff — 20° vertical drop in single rotation	CONFIRMED
2024.88	70.6 → 73.3 → 74.7 → 74.5 → 73.8	Clean peak — cycle maximum then rollover	CONFIRMED

Phase-lock conformance: 5 of 5. The contrast between shifted and unshifted results requires no statistical test. The unshifted lines land in the middle of nowhere. The shifted lines land on every structural feature.

5.3 Turbulence Confirmation

The BSE sawtooth waveform predicts that maximum systemic turbulence occurs at phase boundaries — energy accumulates linearly across the phase window and releases sharply at the transition. If this prediction is physically grounded, the HCS tilt angle should show maximum volatility at the shifted boundaries.

Figure 2. WSO HCS Tilt Angle vs BSE Phase Boundaries, 1976–2025
Unshifted boundaries show no alignment; Hβ-shifted boundaries confirm 5/5 structural features.
BSE phase context | grey dashed = raw boundary | red = Hβ-shifted (+0.88y)



Path length — the sum of absolute differences in L_av across a five-rotation window — measures total kinetic movement of the HCS at each boundary:

Shifted Boundary	Central L_av	Path Length (degrees)	Description
1981.88	47.7°	10.8	Moderate — bottoming phase
1992.38	23.9°	36.1	Extreme volatility — highest in set
2003.88	56.9°	20.1	High jitter — momentary destabilization

Shifted Boundary	Central L_av	Path Length (degrees)	Description
2014.88	52.5°	26.1	Massive cliff — second highest in set
2024.88	74.7°	5.0	Stable — cycle peak before rollover

The two strongest BSE phase transitions produce the two highest HCS path lengths in the dataset. At the 1991.5 boundary, the shifted path length is 36.1° versus 10.8° unshifted — a 234% increase. At the 2014.0 boundary, the shifted path length is 26.1° versus 7.1° unshifted — a 267% increase.

The physical heliospheric field is maximally turbulent precisely where the BSE sawtooth predicts maximum energy release. The mechanism is consistent with Alfvén's frozen-in theorem: field lines carry accumulated magnetic tension across the phase window until the tension exceeds the plasma's ability to maintain the frozen-in configuration, producing rapid reorganization visible as tilt angle volatility.

6. Constraining Evidence: Interior Resonance

Two tests of whether the BSE fundamental period (10.75 years) arises from Alfvén standing wave resonance of the solar interior returned null results. The tachocline cavity resonates at approximately 14.6 days — a factor of 270× too fast. The convection zone produces resonances in the minutes-to-hours range.

These null results are informative. They establish that the BSE clock is a dynamo phenomenon — set by flux transport and differential rotation — that Alfvén waves carry into the heliosphere. The waves propagate the clock. They did not generate it. The mechanism is expression, not resonance.

7. Cross-Scale Consistency of Hβ

The 0.88-year constant confirmed in the HCS record is not an isolated measurement. A consistent fractional ratio of approximately 3.5–4.1% of the operative cycle period appears across four physically independent domains:

Measurement	Value	Cycle Scale	Ratio	Domain
BSE constant vs G1 period	0.88y vs 21.5y	Primary solar cycle	4.1%	Temporal

Measurement	Value	Cycle Scale	Ratio	Domain
BSE Aeon vs Precession of Equinoxes	24,768y vs 25,772y	Aeon scale	3.9%	Astronomical
BSE Aeon vs Planetary Resonance Node	24,768y vs 25,539y	Aeon scale	3.0%	Computational
HCS systematic phase offset	0.88 years	Primary solar cycle	4.1%	Heliospheric
Orbital velocity ratio at Jupiter boundary	1.032	Solar system scale	3.2%	Spatial
BSE split regime spatial correction	3.5% applied	Planetary system	3.5%	Spatial

Six independent measurements. Four physical domains. Four orders of magnitude in timescale. Monte Carlo testing confirms the clustering is statistically incompatible with chance ($p < 0.00005$ under log-normal null). The full cross-domain derivation is reported in the companion master paper (Khan, 2026b).

The Heliospheric Propagation Constant is not a fitted parameter. It is a scale-invariant structural property of the system — the fraction of any cycle period that the receiving medium requires to fully express the mechanical clock's state change.

8. Forward Prediction

The BSE predicts the next phase boundary at 2035.0 (shifted expression at ~2035.88). If the model is correct, the WSO HCS tilt angle record should show a structurally meaningful feature — a trough, cliff, peak, or directional reversal — at or near that date, consistent with the sawtooth energy release pattern observed at the five preceding boundaries. The prediction is registered here before the event occurs.

9. Discussion

The result reported here is narrow in scope and broad in implication. Five dates were predicted by a deterministic model. Five dates were confirmed against an instrument physically independent of the model's validation data. The offset between prediction and confirmation is the same constant — 0.88 years — measured independently across eight proxy domains over 172 years.

The narrowness is deliberate. This paper does not claim to explain the solar dynamo, resolve the interior mechanism that enforces the 10.75-year period, or characterize the full complexity of solar-terrestrial coupling. It claims that a deterministic model with a single input and zero free parameters predicts when the Heliospheric Current Sheet will show structural transitions — and it does.

The primary open theoretical question is the formal derivation of the 10.75-year fundamental from magnetohydrodynamic first principles. The BSE identifies the period empirically. Why the solar dynamo produces harmonic nodes at these specific integer ratios is a question for the MHD community. That it does so is the empirical finding. The pattern is confirmed. The derivation is the next required step — the same bridge Newton built for Kepler's empirically confirmed orbital laws.

10. Data Availability

The WSO HCS tilt angle data used in this study is publicly available from the Wilcox Solar Observatory, Stanford University (http://wso.stanford.edu/). All BSE datasets, model parameters, the mechanical calendar, the interactive calendar readout, and the complete validation archive are deposited at https://zenodo.org/communities/bicameral-solar-engine/.

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