SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 4, (2026), pp. 2250-2255
Open Access. Online & Print

DOI: 10.5281/zenodo.12426305

ACTIVE METRIC CONTROL VIA INFORMATIONAL STATE MANIPULATION: SPECIFICATION OF A CAUSAL-SYMMETRIC WARP DRIVE

Elias Rubenstein[1]

Independent Researcher, Fort Lauderdale, Florida, USA

Received: **05/12/2025**
Accepted: **14/02/2026**

Corresponding Author: Elias Rubenstein (science@elias-rubenstein.com)

ABSTRACT

Faster-than-light travel within General Relativity is obstructed by the need for effective sources with negative energy density or, equivalently, by the need to violate the null energy condition in the region that shapes the warp bubble. This paper proposes a warp-drive specification in which the required effective energy scale is generated from controlled non-equilibrium quantum information. The central resource measure is the quantum relative entropy between a local quantum state and a chosen local equilibrium state. An informational energy density is introduced that is proportional to this relative entropy and to a conductivity-like control parameter, and an associated effective stress–energy tensor is derived from a generally covariant scalar-field action at the level of an effective description. The coupling ρinfo = ακD(ρ‖σZ) is therefore treated as a phenomenological EFTlevel parametrization below a physical ultraviolet cutoff ΛCutoff, with a serving as a dimension-setting conversion scale fixed by matching to a reference energy density. The resulting parameterization yields a quantitative scaling law: the minimum relative entropy required for a superluminal warp bubble scales as the square of the bubble radius divided by the wall thickness, multiplied by the squared target speed in units of the speed of light. A chronology-protection design criterion is formulated in terms of a smooth, strictly monotonic control profile across the bubble wall, connecting controllability to standard causality requirements in Lorentzian geometry. For the minimal k-essence baseline used to derive the effective stress–energy tensor, NEC violation does not occur for the ghost-free sign choice; any stable NEC-violating implementation therefore requires an extended effective completion, while the present result is primarily a consistency and specification analysis. The inferred parameter requirements remain far beyond current technological capabilities.

KEYWORDS: General Relativity, Quantum Relative Entropy, Null Energy Condition Violation, Quantum Information Energy Density.

1 INTRODUCTION AND THEORETICAL CONTEXT

1.1 Notation and Assumptions

Symbol	Description	Unit (effective description)
κ	Informational conductivity (control parameter)	$[\text{Time}]^{-1} \sim s^{-1}$
κRef	Reference rate used to render κ dimensionless in the $c_{\text{eff}}(\kappa)$ ansatz	$[\text{Time}]^{-1} \sim s^{-1}$
η	Dimensionless coupling parameter in the $c_{\text{eff}}(\kappa)$ ansatz (assumed O(1))	Dimensionless
σZ	Local equilibrium reference state	Dimensionless density operator
ρ	Local quantum state	Dimensionless density operator
$D(\rho\|\sigma_Z)$	Quantum relative entropy, $D(\rho\|\sigma_Z)$	Dimensionless (nats)
ρinfo	Informational energy density	[Energy]/[Volume]
Θinfo$_{\mu\nu}$	Informational stress–energy tensor	[Energy]/[Volume]
a	Conversion factor in $\rho_{\text{info}} = a\kappa D(\rho\|\sigma_Z)$	[Energy] · [Time]/[Volume]
I	Informational order parameter field (scalar)[1]	Dimensionless (effective)
Linfo	Informational-sector Lagrangian density	[Energy]/[Volume]

1.2 Assumptions and Validity Scope

- Effective description below a high-energy cutoff: The framework is treated as an effective description below a near-Planck ultraviolet cutoff. The physical cutoff Λ_{Cutoff} defines a coarse-graining cell size and limits local degrees of freedom in the operational definition of $D(\rho\|\sigma_Z)$.
- Local equilibrium constraint: The reference state σ_Z is a maximumentropy state constrained by locally conserved quantities Z. • Matter sector energy condition: The ordinary matter stress tensor $T_{\mu\nu}^{\text{Matter}}$ is assumed to satisfy the weak energy condition. Any effective violation needed for the warp bubble is attributed to the informational sector $\Theta\text{info}\mu\nu$.

1.3 Relation to Existing Faster-Than-Light Literature

Classical superluminal metric proposals (e.g., Alcubierre [1], Krasnikov [2], Natário [3], and analyses summarized by Visser [4]) face two core difficulties: (i) the need for effective sources that violate the null energy condition in the wall region, and (ii) causality pathologies, including closed timelike curves in certain extended constructions [5].

The present construction retains an Alcubierre-type shift-vector geometry but replaces an *ad hoc* exotic-matter ansatz with an informational source term whose magnitude is parametrized by quantum relative entropy and a conductivity-like scale. This choice is motivated by the established role of relative entropy in quantum statistical mechanics and quantum information theory [13, 14, 15, 16] and by thermodynamic viewpoints on gravity [9, 10, 11, 12].

Two structural elements are emphasized:

1. Source replacement: $\Theta^{\text{info}}{}_{\mu\nu}$ is derived from a covariant action and parametrized by $\rho_{\text{info}} = a\kappa D(\rho\|\sigma_Z)$, interpreting non-equilibrium information as an effective free-energy density scale [6, 7, 8, 16].
2. Causality control: A designed κ-profile is used to formulate a chronologyprotection design criterion, connecting control profiles to standard causality conditions in Lorentzian geometry [22, 23].

Comparison to Recent Literature

Recent work explores physical warp drive models with reduced exoticity requirements [24] and hyperfast soliton constructions [25]. In particular, Lentz (2021) constructs hyperfast configurations within an Einstein–Maxwell–plasma/soliton setting, where the source is modeled in terms of classical field and plasma degrees of freedom. By contrast, the present work treats the sourcing mechanism as an information-theoretically parametrized non-equilibrium sector: relative entropy provides the central resource measure, and κ encodes a control scale that determines the effective sourcing strength at the EFT level. Independently, quantum inequalities place strong limits on sustained negative energy densities in semiclassical settings [26, 27, 28, 29]. The present work does not claim near-term realizability; it isolates a consistent *parametric* specification of the source sector and the associated scaling requirements, complementing classical matter/field constructions by emphasizing source design and controllability rather than proposing a specific plasma or soliton medium.

2. THEORETICAL FOUNDATIONS AND CONSISTENCY CHECK

2.1 Gravity as an Informational Equation of State

A modified Einstein equation with a split source is considered:

$$G\mu\nu = 8\pi G\, T\mu\nu\text{Matter} + \Theta^{\text{info}}_{\mu\nu}). \quad (1)$$

The informational energy density is parametrized as

$$\rho_{\text{info}} = a\kappa D(\rho\|\sigma_Z)\cdot \quad (2)$$

Interpreting relative entropy as an effective free-energy measure is standard in quantum information settings and in bounds relating information and energy [15, 16]. In the present effective description, $D(\rho\|\sigma_Z)$ is understood as an operationally defined coarse-grained quantity at the cutoff scale Λ_{Cutoff}, consistent with the regularization discussion below.

Status of the coupling ansatz

Equation (2) is intentionally introduced as a phenomenological EFT-level coupling rather than as a unique consequence of a microscopic derivation. The role of a is to provide the dimension-setting conversion between a cutoffregularized informational quantity ($D(\rho\|\sigma_Z)$, dimensionless) and an effective energy-density scale. A UV-complete microphysical model that yields (2) from first principles is beyond the scope of the present specification analysis and is deferred to future work; within the EFT logic, the coupling is fixed by matching to a reference energy density scale and by requiring consistency with the assumed cutoff coarse-graining.

Normalization of a

The conversion factor a has dimension [Energy] · [Time]/[Volume]. A reference scale is fixed by matching $a\kappa_{\text{Ref}}$ to the Planck energy density:

$$\alpha\kappa_{\text{Ref}} \sim \rho_{\text{Pl}} = \frac{c^7}{G^2\hbar}. \quad (3)$$

A physical cutoff Λ_{Cutoff} defines the coarse-graining cell volume $V_0 \sim \Lambda^{-}{}_{\text{Cutoff}}{}^3$, recovering Planck scaling in the near-Planck limit.

Covariant Definition and Regularization

In algebraic quantum field theory, relative entropy is well-defined for von Neumann algebraic states [13]. For local quantum field theory, finite coarsegraining (a physical ultraviolet cutoff) effectively limits degrees of freedom per cell; the working assumption is that this renders the local $D(\rho\|\sigma_Z)$ finite and operationally meaningful at the effective level. Related split-property constructions and locality arguments are standard in the algebraic quantum field theory literature [17, 18].

2.2 Informational Stress–Energy Tensor from a Covariant Action

The informational sector is modeled by an effective scalar-field action. A baseline k-essence form [19] is

$$\mathcal{L}_{\text{info}} = K(\kappa) + Q(\kappa)\, X, \qquad X := -\frac{1}{2}\, g^{\mu\nu}\nabla_\mu I \nabla_\nu I. \quad (4)$$

Variation with respect to the metric gives

$$\Theta^{\text{info}}_{\mu\nu} = \mathcal{L}_{\text{info}}\, g_{\mu\nu} - 2\frac{\partial \mathcal{L}_{\text{info}}}{\partial g^{\mu\nu}} = (K + QX) g_{\mu\nu} + Q\, \nabla_\mu I \nabla_\nu I. \quad (5)$$

In this paper, κ is treated as a slowly varying background control parameter in the metric variation; spatial dependence is introduced through a designed profile $\kappa(r_s)$ at the effective level.

General Relativity limit

For constant κ and constant $I(x)$, one has $X = 0$. We fix the vacuum normalization by choosing $K(\kappa) \equiv 0$ in the reference configuration (equivalently, subtracting the constant piece), so that $L_{\text{info}} \to 0$, $\Theta^{\text{info}}{}_{\mu\nu} \to 0$, and (1) reduces to the standard Einstein field equations.

Energy conditions and stability: baseline limitations and required EFT structure

A warp bubble in the Alcubierre class requires effective violation of the null energy condition in the wall region:

$$(T^{\text{Matter}}_{\mu\nu} + \Theta^{\text{info}}_{\mu\nu})_{\mu\nu} n^\mu n^\nu < 0 \text{ for some null } n^\mu.$$

Using (5) and $g_{\mu\nu} n^\mu n^\nu = 0$ for null n^μ,

$$\Theta^{\text{info}}_{\mu\nu}{}_{\mu\nu} n^\mu n^\nu = Q(\kappa)\left(n^\mu \nabla_\mu I\right)^2. \quad (6)$$

Therefore, for the baseline linear kinetic form (4) with $Q(\kappa) \geq 0$ (the conventional sign choice for a ghost-free scalar at the level of quadratic fluctuations), the informational sector cannot violate the NEC. Achieving NEC violation requires either $Q(\kappa) < 0$ (which generically introduces ghost-like instabilities) or a non-minimal effective completion in which NEC violation is compatible with a healthy perturbation spectrum only under model-dependent conditions.

Accordingly, a technically conservative and journal-robust statement is:

- The baseline k-essence form (4) provides a covariant stress–energy tensor and a compact parametrization of control through κ and I.
- A stable realization of sustained NEC violation generically requires an extended effective sector beyond minimal k-essence, for example ghost-condensate or Galileon-type constructions, where stability constraints must be checked explicitly [20, 21].

The subsequent sections focus on specification and scaling requirements at the level of an effective source parametrization, while leaving the full microphysical completion and stability constraints as explicit future work.

Quantum Energy Inequalities

Quantum inequalities constrain time-averaged negative energy in semiclassical quantum field theory settings [26, 27, 29, 28]. The present model treats ρ_{info} as an effective energy density tied to coarse-grained informational measures; whether and how standard quantum-inequality bounds apply depends on whether $\Theta^{\text{info}}_{\mu\nu}$ can be embedded into a standard operator-valued stress tensor satisfying the assumptions of those theorems. This remains an open constraint to be addressed in a microscopic completion.

3. THE WARP MECHANISM: METRIC AND CAUSALITY

3.1 Specification of the Warp Metric gμνWarp and κ-Profile

An Alcubierre-type shift vector $\beta^i = (-v_s(t)f(r_s),0,0)$ is used:

$$\mathrm{d}s^2 = -\left(c^2 - f(r_s)^2 v_s^2\right)\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + 2f(r_s)v_s\,\mathrm{d}t\,\mathrm{d}x, \quad (7)$$

with standard discussions and energy-condition analysis in [1, 4, 3].

A smooth interior-to-exterior κ-profile (along the bubble normal) is

$$\kappa(r_s) = \kappa_{\text{ext}} + (\kappa_{\text{int}} - \kappa_{\text{ext}})\,\frac{1}{2}\left[1 - \tanh\left(\frac{r_s - R}{\delta}\right)\right], \quad (8)$$

where κ_{int} is the interior conductivity, κ_{ext} is the exterior value, R is the bubble radius, and δ is the wall thickness. This profile is smooth and strictly monotonic across the wall for $\kappa_{\text{int}} \neq \kappa_{\text{ext}}$.

3.2 Effective Invariant Speed ceff(κ)

A schematic running-speed ansatz is adopted to encode the idea that a background control parameter κ can renormalize an effective invariant speed. To ensure dimensional consistency, introduce a reference rate κ_{Ref} and a dimensionless coupling η = O(1) and write

$$c^2_{\text{eff}}(\kappa) = c^2 \left(1 - \eta\left(\frac{\kappa}{\kappa_{\text{Ref}}}\right)^2\left(\frac{\mathcal{R}^2}{\Lambda^4_{\text{Cutoff}}}\right)\right), \quad (9)$$

where R^2 denotes a curvature invariant (e.g., $R_{\mu\nu}R^{\mu\nu}$) and Λ_{Cutoff} is treated as an inverse-length ultraviolet cutoff scale. The causality-relevant assumption is that $c_{\text{eff}}(\kappa)$ is monotonic in κ over the operating range.

3.3 Chronology Protection as a Design Criterion

Conjecture 1 (Chronology-Protection Design Criterion (Sufficient Condition)). *Assume that the κ-profile* (8) *is smooth and strictly monotonic along the bubble normal and that $c_{eff}(\kappa)$ is strictly monotonic in κ over the bubble wall. If, for the resulting controlled geometry* (7)*, there exists a smooth time function T with everywhere timelike gradient (stable causality) and the level sets T = const are Cauchy hypersurfaces, then the spacetime is globally hyperbolic. The monotonic control hypothesis is intended as an engineering-style sufficient condition that constrains lightcone deformations, but a complete proof requires a global causal-structure analysis of the fully controlled metric.*

Proof sketch (status and rationale)

A standard sufficient route to global hyperbolicity is the existence of a smooth time function whose level sets are Cauchy hypersurfaces [22]. The intended role of monotonic control is to suppress the lightcone deformations required to form closed timelike curves in extended constructions, aligning the conjecture with the standard causal hierarchy in Lorentzian geometry [23]. A complete proof requires a detailed causal analysis of the full controlled metric and is treated as a future mathematical task.

4 QUANTITATIVE ANALYSIS AND TECHNICAL SPECIFICATION

4.1 Energy Requirements and Scaling

Classical analyses concentrate the required exoticity in a shell of thickness δ and radius R [1, 4]. Parametrically,

$$\mathcal{E}_{\text{info}} \sim \rho_{\text{eff}} V_{\text{wall}} \sim \mathcal{O}\left(\frac{R^3}{\delta}\frac{v^2}{c^2}\right). \quad (10)$$

Assuming $E_{\text{info}} \sim a\kappa D(\rho\|\sigma_Z)_{\min} V_{\text{wall}}$, one obtains the key scaling:

$$D(\rho\|\sigma_Z)_{\min}(R,v,\delta) \sim \mathcal{O}\left(\frac{R^2}{\delta}\left(\frac{v}{c}\right)^2\right). \quad (11)$$

Concrete estimate (illustrative)

For R = 100m, δ = 10m, and v = 2c, the wall volume is $V_{\text{wall}} \approx 4\pi R^2\delta \approx 1.26 \times 10^6$ m^3. Taking an illustrative equivalent mass density scale $\rho_{\text{eff}} \sim 10^3$ kg/m^3 yields $E_{\text{info}} \sim 10^3 \cdot 1.26 \times 10^6 \cdot 4$ kg $\approx 5 \times 10^9$ kg $\approx 4.5 \times 10^{26}$ J.

This estimate is included to underscore the magnitude gap between formal consistency and realizability, not as a claim of physical attainability.

4.2 Operationalization of a Quantum-Randomness Falsification Bound

Any experimental bound on κ constrains $\rho_{\text{info}} = a\kappa D(\rho\|\sigma_Z)$ and therefore constrains realizability of the source sector. A conceptual protocol is to test a predicted correlation shift $\Delta p \sim \kappa\tau$ in delayed-choice quantum-randomness statistics. For a target $\Delta p \sim$

10^{-16}, a 5σ detection would require $N \sim 10^{34}$ samples, far beyond current capability; however, non-detection still produces an upper bound on κ, which translates into a lower bound on the required $D(\rho\|\sigma_Z)_{\min}$ through (2) and (11).

5 DISCUSSION AND OUTLOOK

The proposed parameterization recasts superluminal sourcing as controlled non-equilibrium information engineering. The remaining tasks fall into three categories:

- Mathematical consistency: Compute fully self-consistent solutions of the coupled system $G_{\mu\nu} = 8\pi G(T_{\mu\nu}{}^{\text{Matter}}+\Theta^{\text{info}}{}_{\mu\nu})$, where κ and I arise dynamically rather than by prescription.
- Physical constraints: Map the effective sector to known semiclassical constraints (including quantum energy inequalities) and derive observational/experimental bounds [26, 27, 29, 28].
- Stability and completion: Specify an extended informational effective sector that permits NEC violation without pathological degrees of freedom, and verify stability conditions explicitly [20, 21].

6 CONCLUSION

By deriving $\Theta^{\text{info}}{}_{\mu\nu}$ from a covariant action, presenting the relative-entropy scaling (11), and formulating a chronology-protection design criterion in terms of a controlled κ-profile, this work provides a formal specification pathway for informationally sourced warp-metric control, while highlighting that realizability and a full microscopic completion remain far beyond present technology.

Appendix A: Brief Derivation of the Relative-Entropy Scaling

The total required exotic energy scales with the wall volume and required effective density [1, 4]:

$$\mathcal{E}_{\text{info}} \sim \rho_{\text{eff}} V_{\text{wall}} \sim \mathcal{O}\left(\frac{R^3}{\delta}\frac{v^2}{c^2}\right). \quad (12)$$

Using Einfo ~ $\alpha\kappa D(\rho\|\sigma Z)\min V$wall gives

$$D(\rho\|\sigma_Z)_{\min} \sim \mathcal{O}\left(\frac{R^2}{\delta}\left(\frac{v}{c}\right)^2\right). \quad (13)$$

REFERENCES

M. Alcubierre, "The warp drive: hyper-fast travel within general relativity," *Classical and Quantum Gravity*, 11(5), L73–L77 (1994). doi: https://doi.org/10.1088/0264-9381/11/5/001

S. Krasnikov, "Hyperfast travel problem," *Physical Review D*, 57(4), 4760–4766 (1998). doi: https://doi.org/10.1103/PhysRevD.57.4760 [3] J. Natário, "Warp drive with zero expansion," *Classical and Quantum Gravity*, 19(6), 1157–1165 (2002). doi: https://doi.org/10.1088/02 64-9381/19/6/308

M. Visser, "Warp drive basics," *Classical and Quantum Gravity*, 15(6), 1767–1791 (1998). doi: https://doi.org/10.1088/0264-9381/15/6/0 24

A. E. Everett, "Warp drive and causality," *Physical Review D*, 53(12), 7365–7368 (1996). doi: https://doi.org/10.1103/PhysRevD.53.7365

E. T. Jaynes, "Information theory and statistical mechanics," *Physical Review*, 106(4), 620–630 (1957). doi: https://doi.org/10.1103/Phys Rev.106.620

R. Landauer, "Irreversibility and heat generation in the computing process," *IBM Journal of Research and Development*, 5(3), 183–191 (1961). doi: https://doi.org/10.1147/rd.53.0183

S. Deffner and C. Jarzynski, "Information Processing and the Second Law of Thermodynamics: An Inclusive, Hamiltonian Approach," *Physical Review X*, 3, 041003 (2013). doi: https://doi.org/10.1103/Phys RevX.3.041003

T. Jacobson, "Thermodynamics of spacetime: the Einstein equation of state," *Physical Review Letters*, 75(7), 1260–1263 (1995). doi: https: //doi.org/10.1103/PhysRevLett.75.1260

E. Verlinde, "On the origin of gravity and the laws of Newton," *Journal of High Energy Physics*, 2011(4), 029 (2011). doi: https://doi.org/ 10.1007/JHEP04(2011)029

M. Van Raamsdonk, "Building up spacetime with quantum entanglement," *General Relativity and Gravitation*, 42(10), 2323–2329 (2010). doi: https://doi.org/10.1007/s10714-010-1034-0

A. C. Wall, "The generalized second law implies a quantum singularity theorem," *Classical and Quantum Gravity*, 30(16), 165003 (2013). doi: https://doi.org/10.1088/0264-9381/30/16/165003

H. Araki, "Relative entropy for states of von Neumann algebras," *Publications of the Research Institute for Mathematical Sciences*, 11(3), 809– 833 (1976). doi: https://doi.org/10.2977/prims/1195191148

M. Ohya and D. Petz, *Quantum Entropy and Its Use*, Springer (1993). ISBN: 978-3-642-86088-3

V. Vedral, "The role of relative entropy in quantum information theory," *Reviews of Modern Physics*, 74, 197–234 (2002). doi: https://doi.or g/10.1103/RevModPhys.74.197

H. Casini, "Relative entropy and the Bekenstein bound," *Classical and Quantum Gravity*, 25(20), 205021 (2008). doi: https://doi.org/10.1 088/0264-9381/25/20/205021

S. Doplicher and R. Longo, "Standard and split inclusions of von Neumann algebras," *Inventiones Mathematicae*, 75, 493–536 (1984). doi: https://doi.org/10.1007/BF01403003

D. Buchholz and E. H. Wichmann, "Causal independence and the energy-level density of states in local quantum field theory," *Communications in Mathematical Physics*, 106, 321–344 (1986). doi: https: //doi.org/10.1007/BF01211129

C. Armendariz-Picon, V. Mukhanov, and P. J. Steinhardt, "Essentials of k-essence," *Physical Review D*, 63(10), 103510 (2001). doi: https: //doi.org/10.1103/PhysRevD.63.103510

N. Arkani-Hamed, P. Creminelli, S. Mukohyama, and M. Zaldarriaga, "Ghost condensation and a consistent infrared modification of gravity," *Journal of High Energy Physics*, 2004(05), 074 (2004). doi: https: //doi.org/10.1088/1126-6708/2004/05/074

A. Nicolis, R. Rattazzi, and E. Trincherini, "The Galileon as a local modification of gravity," *Physical Review D*, 79(6), 064036 (2009). doi: https://doi.org/10.1103/PhysRevD.79.064036

A. N. Bernal and M. Sánchez, "Smoothness of time functions and the metric splitting of globally hyperbolic spacetimes," *Communications in Mathematical Physics*, 257, 43–50 (2005). doi: https://doi.org/10.1 007/s00220-005-1312-6

S. W. Hawking and G. F. R. Ellis, *The Large Scale Structure of SpaceTime*, Cambridge University Press (1973). ISBN: 978-0521099066

A. Bobrick and G. Martire, "Introducing physical warp drives," *Classical and Quantum Gravity*, 38(10), 105009 (2021). doi: https://doi.org/ 10.1088/1361-6382/abdf6e

E. W. Lentz, "Breaking the warp barrier: hyper-fast solitons in Einstein– Maxwell–plasma theory," Classical and Quantum Gravity, 38(7), 075015 (2021). doi: https://doi.org/10.1088/1361-6382/abe692

[26] L. H. Ford and T. A. Roman, "Averaged energy conditions and quantum inequalities," Physical Review D, 51, 4277–4286 (1995). doi: https: //doi.org/10.1103/PhysRevD.51.4277

L. H. Ford and T. A. Roman, "Restrictions on negative energy density in flat spacetime," *Physical Review D*, 55, 2082–2089 (1997). doi: https://doi.org/10.1103/PhysRevD.55.2082

M. J. Pfenning and L. H. Ford, "The unphysical nature of 'warp drive'," *Classical and Quantum Gravity*, 14(7), 1743–1751 (1997). doi: https: //doi.org/10.1088/0264-9381/14/7/011

C. J. Fewster and T. A. Roman, "Null energy conditions in quantum field theory," *Physical Review D*, 67, 044003 (2003). doi: https://do i.org/10.1103/PhysRevD.67.044003