

Antimatter and Spacetime Propulsion Research Proposal

Formal assessment and phased government and private funding plan

From Mars to the Stars

Robert J. Hathaway III

Independent researcher and proposed Program Architect

First issued 13 October 2026

Revision 1.1 | 18 October 2026

Prepared for NASA and other government research programs, research institutions, philanthropic sponsors and commercial technology partners.

Decision requested: Support a nine-month research study with a total planning budget of \$500,000, followed by evidence-based decisions on a five-year experimental platform. The proposed initial financing comprises a \$225,000 mission study for NASA consideration and a separate \$275,000 privately sponsored research package.

Program ambition: An interstellar future within a generation, enabled by antimatter engineering, progress in spacetime physics, spacecraft capability and increasingly powerful research intelligence.

Research foundation: The accompanying 27-page paper, Antimatter and Spacetime Propulsion: An Integrated Research Architecture, revised 12 October 2026, provides the technical baseline, calculations and conditional roadmap. [T0]

Participation status: This proposal requests resources and collaboration. External people and organizations are identified for prospective engagement; none is represented as a committed participant or funder. Their work is credited separately from Hathaway's conceptual contributions.

The full proposal is for sponsor discussion and partnership development. Agency submissions must use the applicable solicitation format and confirmed institutional information.

Research archive <https://hathaway-architect.com/from-mars-to-the-stars>

Contact <mailto:contact@hathaway-architect.com>

Contents and proposal guide

The proposal combines a bounded first study with the full research agenda, long-term investment options and a source register. Page numbers refer to this edition. Word headings and the PDF bookmarks provide section navigation.

Proposal component	Page
Executive assessment and North Star	3
Primary research and intellectual merit	5
Representative mission and research approach	6
Antimatter spacetime and spacecraft work	8
Starship cryogenics and antihydrogen storage	9
Cryogenic research milestones and acceptance	10
Prospective SpaceX partnership and transition	13
AGI ASI quantum computing and laboratories	14
First study deliverables and acceptance	16
Five ten and twenty year roadmap	17
Initial and five year budgets	19
Government private and milestone funding	22
Governance people and RACI	25
Evaluation and risk assessment	29
Commercial transition and data management	31
Author qualifications and launch plan	33
Complete goal and quantitative target registers	35
Sponsor decisions	37
Technical funding partner and author references	38
Cryogenic references and revision history	44

Technical references use T identifiers; funding and administrative references use F identifiers; partner and author references use P and B identifiers. The goal crosswalk retains every research branch and target in the accompanying paper.

Executive assessment and funding decision

I propose a coordinated research program that makes each advance in antimatter handling, source physics and scientific computing usable by the wider architecture. The first investment would produce independently checked models, a specific mission assessment, experimentally defined next steps and a defensible budget for subsequent development.

The paper establishes an architecture and a quantitative planning basis. A funded study should now determine which combinations of fuel, confinement, conversion, thermal management and research automation can provide a useful spacecraft capability. The spacetime branch will assess candidate sources and their mathematical consistency. A negative or limiting result is an accepted scientific outcome when it is reproducible and narrows the design space.

Assessment area	Present position	Investment implication
Architecture	Documented system decomposition and roadmap. [T0]	Suitable starting point for feasibility and partner review.
Antimatter engineering	Laboratory trapping and transport demonstrated by others; condensed fuel remains proposed. [T13–T24]	Fund measured capture, ordinary-material analogues and system trade studies first.
Spacetime transport	Published geometries and unresolved source, energy-condition and control requirements. [T1–T12]	Fund rigorous theory and verification before actuator construction.
AI and automation	Evidence for coding, control and laboratory assistance; general recursive ASI is a scenario. [T28–T35]	Measure verified research throughput; preserve an implementable baseline.
Program execution	Lead host, specialist effort and access agreements must be established.	Release experimental funds after staffing, facilities and review are in place.

Recommended investment sequence

Authorize the initial study and retain options for larger support. The NASA-facing study is a complete, independently executable project. Private funds support additional architecture, spacetime and automation work and an ordinary-material test package. Later commitments are contingent on the findings; private money is not presented as a required match or as payment for the same costs.

The assessment is a program planning judgment, not an external peer-review determination. The requested first study includes independent scientific review to establish the basis for the next investment decision.

North Star and program goals

North Star: Develop verified scientific and engineering capabilities that allow humanity to extend a peaceful, productive civilization beyond Earth and toward the stars, while advancing broadly accessible intelligence and human flourishing.

An interstellar future within a generation is the strategic ambition. Launch readiness, arrival at a distant destination and faster-than-light capability are different milestones. Calendar targets organize investment; observed results determine technical advancement.

Goal	Outcome sought	Measure of progress
G1 Antimatter supply	More useful captured inventory per unit energy and facility time.	Delivered particles per joule; uptime; reproducible yield.
G2 Fuel storage	Trapped atoms, then anti-molecules and verified microcrystals; optional antihelium cushion.	Lifetime, temperature, losses, transfer survival and measured advantage over simpler storage.
G3 Regulated power	Counted delivery with a complete energy and heat balance.	Packet inventory, conversion fraction, timing and shutdown response.
G4 Spacetime physics	A physically sourced and controllable transport model, or rigorous limits on candidates.	Full tensor, observer tests, formation, stability and measurable prediction.
G5 Spacecraft	Uncrewed precursor capabilities and eventual interstellar vehicles.	Full mass, propulsion, thermal, communications and mission budgets.
G6 Recursive intelligence	Research systems that improve their tools and their own research capability.	Verified outcomes per dollar and elapsed time, including independent replication.
G7 Human advancement	Useful science, productive tools and public knowledge throughout development.	Open results, training, applications and peaceful-use outcomes.

All seven goals remain in the program. The first award evaluates a bounded mission and selected research interfaces; it does not purchase a functioning warp ship. The complete target register and source-paper crosswalk appear in the appendices.

Primary research and intellectual merit

My primary research agenda is philanthropic semantic AGI/ASI built around recursively self-improving intelligence. I began pursuing this conception in 1980. The proposed program applies that agenda to scientific discovery and engineering: improved intelligence develops better representations, algorithms and experimental strategies, then uses validated improvements to strengthen the next research cycle. [B1; T0]

I distinguish my conceptual inputs from the mathematical and experimental work cited in the paper. My inputs include frozen antihydrogen pellets, an antihelium cushion, regulated antimatter flow and accelerated AI-enabled development, together with the selection and integration of spacetime research references. The intended contribution is an integrated architecture and research method. Publication priority, patent novelty and experimental validation are separate questions.

Research hypotheses

- H1 A joint capture, cooling, confinement and transfer model can identify better delivered-yield combinations than optimizing isolated modules.
- H2 Explicit source models and independent tensor calculations can distinguish useful spacetime candidates from coordinate or observer artifacts.
- H3 Semantic representations of assumptions, units, interfaces and evidence can reduce invalid AI-generated research proposals and accelerate verified iteration.
- H4 Autonomous experimental planning coupled to repeatable measurements can convert software gains into physical research gains.
- H5 A packet-regulated antimatter subsystem may provide mission benefit after the full containment, conversion, thermal and supply costs are included.

Innovation assessment

The feasibility study will test novelty at the system and method levels against prior NIAC studies, NASA propulsion concepts and current tools. A combination of known components is valuable only if the analysis establishes a materially different capability, a useful interface or a validated improvement. The proposal therefore includes a prior-work comparison and explicit baseline designs.

The author's research chronology and conceptual inputs accompany the technical baseline. A 1996 primary public record documents Hathaway's editorial leadership of Object Currents. The agency biographical package will assemble dated research notes, publications and professional appointments. [B1–B3]

Representative NASA mission and quantified trade study

The NASA-facing reference mission is a proposed uncrewed science probe to 200 astronomical units, with a 100 kg science payload and a planning objective of arrival within 30 years of launch. It would measure the outer heliosphere and interstellar environment. A notional 1,000 kg spacecraft after injection provides a common system boundary for comparing propulsion assist and high-power science operations. These are study assumptions, not an approved NASA mission or a demonstrated vehicle.

Planning allocation	Mass
Science payload	100 kg
Bus avionics communications and attitude control	220 kg
Working fluid for the propulsion comparison	300 kg
Fuel containment cryogenics magnets and shielding	250 kg
Radiators structures and growth allowance	130 kg
Total comparison spacecraft	1,000 kg

The approximate distance divided by travel time is 31.6 km/s. A trajectory analysis must add escape conditions, planetary assists, acceleration periods and operational constraints. The comparison will include available conventional approaches and advanced nuclear alternatives with the same payload and mission boundary.

First useful energy calculation

A 10 kW useful-output subsystem operating for a cumulative 100 hours supplies 3.6 GJ. At the paper's illustrative 30 percent conversion fraction, direct annihilation consumes about 66.8 micrograms of antimatter plus equal ordinary matter. This excludes refrigeration and other overhead. That supply is far beyond present small laboratory inventories and is a central feasibility constraint. [T0]

For scale, a 30 km/s velocity change with 300 kg of expelled working fluid and a 1,000-to-700 kg mass ratio implies approximately 84 km/s effective exhaust velocity in a simple nonrelativistic rocket calculation. An idealized exhaust-energy estimate is about 1.06 TJ, equivalent to roughly 20 mg of antimatter at 30 percent useful energy capture. It is a screening bound, not a complete propulsion model. Antimatter-assisted nuclear options need a separate gain and mass analysis.

The study asks whether the complete system can outperform alternatives, and under what supply assumptions. It will quantify mass, power, volume, useful impulse and uncertainty rather than claim a mission benefit in advance.

Integrated strategy and work packages

The strategy is to share computing, metrology and system interfaces across research branches while preserving independent advancement criteria. Fuel and source physics can mature at different rates. Conventional power runs early experiments; a future field actuator receives antimatter power only after a physical coupling is validated.

Package	Scope	Primary products
WP1 Fuel supply and storage	Capture, deceleration, cooling, atoms, molecules, pellets, cushion concepts and staged cryogenic storage.	Delivered-yield model; storage comparison; qualified experiment specifications.
WP2 Spacetime sources	Metrics, full tensors, physical matter models, formation and stability.	Independent calculations; candidate exclusions or source-based test predictions.
WP3 Spacecraft and power	Regulated reaction energy, shielding, heat rejection, cryogenic infrastructure, mission and vehicle engineering.	Energy ledger; full mass and mission trade; uncrewed test architecture.
WP4 Recursive AI	Semantic representations, research agents, evaluator improvement and tool optimization.	Versioned agent workflow; held-out tests; measured verified throughput.
WP5 Quantum and laboratories	Selected quantum kernels, robotic experiments and distributed facilities.	Equal-accuracy comparisons; automated test loop; provenance and calibration.
WP6 Verification and integration	Independent review, systems engineering, acceptance criteria and data.	Reproducibility releases; milestone decisions; costed next-stage plan.
WP7 Management and transition	Host administration, partnerships, finance, training and commercial applications.	Agreements; grant reporting; sponsor updates; transition and licensing plans.

Investment principles

Fund a claim only with a stated source and test. Fund hardware only with an adequate inventory, load and measurement model. Keep useful intermediate outputs available to research and industry. Expand the program when independent results support it, and redirect work when a candidate fails.

A common model library will record interfaces in units that cannot be confused: stored energy, average power, packet mass, manufacturing electricity, useful impulse and rejected heat. Each work package reports both its own progress and the constraints it imposes on the whole vehicle.

Antimatter supply storage and regulated delivery

WP1 begins with a source-to-delivery accounting model. It will integrate production spectrum, collection acceptance, cooling, trap loading, loss and transfer. CERN's trapping and transportation results establish relevant laboratory precedents; the proposal does not assume access to their facilities or inventory. [T13–T18; P2–P4]

Fuel research sequence

- Reproduce charged-particle and anti-atom inventory calculations and characterize delivered yield under stated facility conditions.
- Design ordinary hydrogen analogues for noncontact suspension, temperature control, charging and delivery.
- Define independent milestones for anti-molecule formation, cluster survival and verified solid molecular antihydrogen.
- Compare a bare microcrystal with an optional antihelium jacket or cushion. Require a quantified benefit that outweighs its production and confinement costs.
- Model counted packets and a transfer stop command, then validate a power ledger against measurement before flight-scale regulation.

The antihelium branch preserves Hathaway's design input and follows successful molecular storage. A superfluid analogy can motivate thermodynamic studies, but the outer antimatter surface still requires independent confinement and heat removal. NASA's ordinary hydrogen-in-helium work informs analogue design. [T19; T23–T24]

Acceptance measures

Reports will state inventory, loss rate, pressure and temperature for each species; transfer survival; packet count or calibrated mass; deposited and escaping energy; and post-command delivered inventory. Cryogenic analysis adds refrigeration power, heat leakage and sublimation loss. A first antimatter measurement requires an approved host experiment and a complete diagnostic chain. The first nine-month private package uses ordinary-material tests and design work; it budgets no bulk antimatter purchase.

Partners and financing

Prospective expertise includes ALPHA, BASE and the UC San Diego positron group. Institutional review determines access and cost. Relevant future routes include DOE accelerator topics, laboratory partnerships, eligible SBIR/STTR component projects, specialist corporate research contracts and science philanthropy. Facility access can reduce cash needs but is not a cash award. [F5–F8; P2–P4]

Starship cryogenics and antihydrogen storage

Starship's cryogenic infrastructure is a relevant engineering precedent for WP1 and WP3. Its subcooled liquid methane and oxygen are intended for Moon and Mars transportation. A 2025 NASA-SpaceX study reports the transfer of multiple metric tons of liquid oxygen between tanks within one Starship in flight. The transferable knowledge concerns thermal-fluid modeling, vapor control and low-gravity operations; it is not a demonstration of antimatter storage or transfer between two spacecraft. [T36; P7]

Material or system	Reference temperature	Interpretation
Liquid methane	About 111 K / -162 °C	Normal boiling point reference; Starship uses subcooled fuel.
Liquid oxygen	About 90 K / -183 °C	Normal boiling point reference; actual operating conditions differ.
Solid molecular hydrogen	Near 14 K / -259 °C	Low-pressure phase reference; useful storage may need lower temperature.
Webb MIRI cooling	Below 7 K	Demonstrated spacecraft refrigeration precedent, not an antimatter device.

The table compares temperature regimes, not interchangeable equipment specifications. Normal hydrogen thermodynamics guide the expected antihydrogen analogue under matter-antimatter symmetry. Methane and oxygen refrigeration experience alone does not establish an adequate hydrogen or antihydrogen cold stage. [T37-T39]

Formation and confinement requirements

The condensed-fuel option is solid molecular antihydrogen, anti-H₂. CERN has laser-cooled individual trapped antihydrogen atoms to energies corresponding to about 0.012 K, but low atomic kinetic energy alone does not establish molecules, a dense phase or a pellet. The research must establish molecular association, removal of binding and condensation heat, noncontact nucleation and survival. [T13; T19; T40]

A solid pellet remains reactive with ordinary matter. Its confinement and extraction require a separate field-based design. The optional antihelium cushion preserves Hathaway's concept but adds production and external-confinement requirements; it cannot supply permanent refrigeration. Ordinary helium may cool surrounding equipment without contacting the antimatter. [T19; T23]

Cryogenic research milestones and acceptance

The proposed bridge combines spacecraft thermal engineering with noncontact fuel research. SpaceX and NASA results inform insulation, thermal modeling, low-gravity transfer and eventual logistics. Lower-temperature cryocoolers and hydrogen experiments inform the cold stage. The antimatter transfer path requires dedicated confinement; ordinary propellant plumbing cannot directly handle it. [T19; T23; T36-T41]

Stage and link	Research task	Required evidence
C1 Thermal model D2 D4 / M1	Compare staged shields, refrigeration, residual gas and parasitic loads using public data.	Heat and electrical-power balances; mass estimate; uncertainty and loss assumptions.
C2 Ordinary analogue D4 D6 / M3	Use a qualified host for hydrogen particle formation, noncontact suspension and metering tests.	Calibrated temperature, sublimation, heat input, position stability and transfer survival.
C3 Antimatter formation M4 M5	Study anti-molecule formation, clusters and condensed phases in an agreed facility.	Species identification, formation yield, survival and demonstrated confinement.
C4 Flight storage M7	Qualify a dedicated module only after useful storage and adequate supply are demonstrated.	Thermal-vacuum, vibration and acceleration performance; complete mission budget.

NASA experiments have formed ordinary hydrogen particles in liquid helium. Those results support analogue design but do not establish wall-free antimatter nucleation. Bare pellets remain the reference comparison for the optional antihelium cushion. Tests must measure whether any cushion reduces total losses and control demand enough to justify its additional inventory and complexity. [T19; T23]

The AM lead owns storage physics and the cold-stage model; SE owns spacecraft integration and the full power budget. AI supports parameter search and experiment planning, while IV independently checks the results. Validated local controllers retain confinement and rapid fault response.

C1 and the design of C2 are included within the existing study analysis. Actual cryogenic tests require quoted host access and a costed equipment scope. The \$500,000 study request is retained; no Starship flight, bulk antimatter, new cryogenic facility or unconfirmed partner contribution is included.

Spacetime physics and the path to a field demonstrator

WP2 evaluates the research of Lentz, Bobrick and Martire, Fell and Heisenberg, Fuchs and colleagues, and subsequent investigators within their stated assumptions. General relativity couples the complete stress-energy tensor to geometry. Positive energy for one observer family does not establish every relevant energy condition or a realizable physical source. [T1–T12]

Theory and verification tasks

- Reproduce published reference cases using independent symbolic and numerical implementations.
- Test the complete tensor over the relevant observer directions and quantify numerical errors.
- Evaluate matter, electromagnetic or quantum-field source equations, conservation, boundary conditions and their coupled dynamics.
- Analyze causal formation, available control channels, horizons, perturbation growth, radiation and shutdown.
- Search source-based alternatives and distinguish real gravitational transport from optical or condensed-matter analogues.

The paper retains a later hypothetical 1 GJ-to-1 TJ demonstrator envelope. It implies about 18.5 micrograms-to-18.5 milligrams of antimatter at the illustrative conversion fraction. Relative to the cited Fell–Heisenberg example, it would require roughly 32–35 orders of magnitude less field energy or an entirely different validated mechanism. This is a design question to investigate, not a theory-established operating range. [T0; T3]

Decision on actuator work

A physical demonstrator is authorized only after a source model gives a testable signal, complete dynamics and a credible energy budget. A replicated field effect then precedes scaled uncrewed transport. Crewed operation requires a further program. The first funded outcome is a verified candidate analysis or a published limitation.

Partners and financing

Applied Physics is a prospective research and grant contact. Its advertised Warp Fund seeks concrete advances in physical warp-drive theory, with preference for relevant doctoral or publication experience. A named specialist partnership could support a narrow application. Fundamental-physics programs at universities, Simons Targeted Grants and FQxI are other routes to assess for fit. [F4; F11–F12; P1]

Spacecraft engineering mission integration and power

WP3 converts laboratory capabilities into a complete vehicle assessment. Its initial design uses uncrewed flight and a specific mission boundary. Conventional propulsion remains available while antimatter power and source physics are investigated independently.

Spacecraft functions

The mission model includes launch and injection interfaces, propellant and fuel replenishment assumptions, structures, guidance, navigation, communications, autonomous operation, radiation protection, heat rejection and end-of-mission behavior. Longer-term work evaluates orbital refueling, assembly, shipyards and deep-space habitats. A possible warp-capable architecture preserves separate crew habitat, engineering hull and field-generation interfaces; it remains dependent on verified source physics.

Power conversion and thermal design

Compare direct deposited heat, charged-product momentum transfer and antimatter-assisted fission or fusion. Their efficiencies and usable products differ; each needs a separate model. Carry photons, secondary particles and escaping neutrinos in the energy and radiation ledgers. A magnetic nozzle cannot be assumed to direct gamma rays. [T19–T21]

At the illustrative 30 percent useful conversion fraction, continuous 1 MW output consumes about 0.585 g of antimatter each year. If all remaining energy is deposited onboard, it rejects about 2.33 MW of heat. The paper's radiator estimates are about 5,645, 353 and 70 square metres at 300, 600 and 900 K, respectively. These are effective emitting areas with stated emissivity and view assumptions; support structures and cryogenic cooling add costs. [T0]

Qualification sequence

A counted laboratory pulse precedes measured conversion, a ground integrated module, environment testing and an uncrewed flight experiment. Each flight proposal must carry full containment, shielding, radiator, launch and mission costs. Short power bursts and sustainable annual manufacturing are distinct requirements.

Partners and financing

Potential collaborators include NASA propulsion and cryogenic researchers, mission-design institutions, advanced-propulsion companies and spacecraft integrators. SpaceX is a prospective engineering and mission partner for the staged approach described in the following section. NASA NIAC supports the initial concept assessment; later NASA technology calls and corporate contracts require a demonstrated mission benefit. Ryan Weed's NIAC work provides a relevant research precedent. [F1-F3; P5; P7; T36]

Prospective SpaceX partnership and transition

SpaceX's published Earth-orbit, Moon, Mars and beyond objectives create strategic overlap with the program's longer-term exploration goals. The company is a prospective engineering partner; Elon Musk and SpaceX leadership are potential strategic contacts. Any role described here is subject to technical review and agreement. [P7]

A partnership should begin with a defined engineering question: can an independently evaluated storage or research-control method improve a measurable thermal, power or operational requirement? A useful conventional cryogenic result can support further collaboration before dense antimatter becomes available. Starship's ordinary-propellant systems provide operational experience and potential future infrastructure; they are not an antimatter-ready vehicle.

Engagement stage	Potential contribution	Evidence before expansion
Technical review	Compare public cryogenic work and review mission interfaces with a relevant engineering team.	A scoped problem, counterpart agreement and independent assessment.
Joint component study	Separately negotiated modeling, instrumentation or ordinary-material experiment; possible in-kind support.	Costed scope, background IP, measured performance and useful partner outcome.
Future flight discussion	Assess launch, module support or spacecraft integration with SpaceX or another qualified provider.	Validated storage, adequate fuel supply, agreed interfaces and a funded flight case.

I would lead the integrated architecture, semantic research model and recursive AI strategy. AM and SE specialists would lead cryogenic and mission validation under the scientific PI. The grants administrator would negotiate any partner agreement. SpaceX engineers, NASA researchers and cryocooler suppliers would receive project duties only through confirmed participation.

D7 will include a concise engagement package with the technical baseline, ordinary-material results where available, quantified benefit, work scope, proposed IP terms and resource request. Corporate research contracts or philanthropy could support a bounded study; agency funds would follow their own solicitation and cost rules. The initial NASA study remains independently executable without a SpaceX commitment.

Advanced antimatter propulsion could extend the program toward interstellar missions. Faster-than-light capability remains a separate source-physics research branch; cryogenic or launch progress does not by itself validate a spacetime actuator.

AGI ASI and recursive exponential research acceleration

WP4 translates my primary semantic AGI/ASI research into an accountable scientific workflow. Its long-term hypothesis is that recursively self-improving intelligence can drive exponential gains in discovery and engineering, contributing to a technological singularity and orders-of-magnitude improvements in human capability. The funded baseline uses available tools and independent experiments; AGI or ASI arrival is not a required first-study milestone.

Proposed research architecture

- Represent equations, units, assumptions, evidence levels and component interfaces in a semantic research graph.
- Use agents to propose source models, improve solver kernels, select experiments, optimize instruments and maintain design alternatives.
- Permit tool improvements only after held-out tests, independent comparison and reproducible evaluation.
- Feed measured results and verified gains into the next model, evaluator and experiment-planning cycle.
- Measure resource use and failure modes alongside successful results, with human investigators accountable for scientific claims.

The long-term integrity architecture includes persistent principles for human protection, equal rights, peaceful use and broad access across improving generations. In this proposal those principles become versioned requirements, change review and auditable research decisions. An immutable ethical intention is a design objective; it is not proof that a self-modifying system is technically guaranteed to preserve it.

Research scenario from the paper	Five years	Ten years	Twenty years
Steady improvement	3–20 times	10–100 times	30–1,000 times
Accelerated AI and automation	10–100 times	100–10,000 times	1,000–100,000 times
Recursive AI breakthrough	100–1,000 times	1,000–100,000 times	10,000–1,000,000 times

These are planning bands for verified research throughput, not forecasts of intelligence or discovery probability. Doubling a selected capability every six months gives about 1,000-fold growth in five years; physical experiments, energy and verification can limit the realized gain. [T0; T28–T31]

Quantum computing autonomous laboratories and cloud resources

WP5 joins classical high-precision computing, AI screening, selected quantum workloads and physical experimentation. It will determine where each layer produces an end-to-end benefit, including data movement, preparation, error correction and measurement.

Layer	First-study use	Acceptance evidence
Classical HPC	Relativity, particle transport, uncertainty and multiphysics reference cases.	Convergence, conservation and agreement with published benchmarks.
AI research agents	Candidate screening, software improvement and experiment selection.	Held-out accuracy and more verified results for a measured cost.
Quantum resources	Small materials or field subproblems with a justified algorithm.	Equal-accuracy comparison including all overhead; retain the best method.
Automated laboratories	Ordinary-material suspension and instrument characterization.	Calibrated repeatability and independent checks of claimed gains.
Distributed cloud	Versioned research queues, data provenance and remote analysis.	Reliable complete runs; local instruments retain their fast control loops.

RIKEN's FugakuNEXT and other AI-oriented computing plans motivate scalable interfaces. Advertised AI precision is not interchangeable with sustained precision for numerical relativity. Quantum roadmaps likewise remain provider targets. The first award rents or seeks allocations of existing resources; it funds no zettascale factory or new quantum computer. [T25–T35]

Potential resource routes

ACCESS allocations and AWS research credits are candidates for reducing computing cost, subject to eligibility and allocation. NVIDIA's academic grant page currently states that it is not accepting new applications, so it belongs on the monitoring list rather than the committed resource plan. Provider sponsorship and institutional quantum partnerships require agreements. [F9–F10; F16]

The AI lead maintains classical fallbacks and reports useful verified experiments per month. Remote AI or quantum services support analysis; latency and connectivity cannot be part of a critical trap-confinement loop.

Nine month study deliverables and acceptance

Month 1 begins when funding and host authorization are effective. NASA and private tasks have separate cost codes and independently useful outputs. The schedule below describes the combined program; the NASA subset is detailed in the funding section.

Deliverable	Timing	Required result
D1 Evidence and baseline register	Months 1–2	Prior-art comparison; reference mission; defined uncertainty and unit conventions.
D2 Mission and energy trade	Months 2–4	Complete system mass and energy model, including refrigeration power; alternative designs; fuel supply sensitivity.
D3 Independent physics assessment	Months 2–6	Two independent calculations on chosen cases; source-model analysis and documented conclusions.
D4 Fuel handling design package	Months 3–6	Capture-to-delivery ledger; pellet and cushion comparison; Starship transferability and staged cooling analysis; ordinary-material experiment design.
D5 Verified AI research workflow	Months 2–7	Reproducible semantic and agent pipeline; held-out tests; baseline versus improved cost and throughput.
D6 Analogue and resource results	Months 5–8	Privately funded ordinary-material measurements if host access is secured, including thermal and suspension data; justified quantum or cloud comparison.
D7 Decision and transition package	Months 8–9	Independent review; reproducibility release; costed next experiment; sponsor-specific follow-on and prospective partner specifications.

Acceptance criteria

The review panel accepts a model when its assumptions are explicit, its code reproduces reference cases, its numerical uncertainty is bounded, and its results can be independently repeated. A feasibility conclusion may be positive, negative or conditional. A mission-benefit claim must include the entire supporting system and a same-boundary alternative. New field effects require measurements beyond the scope of a paper calculation.

Proposed performance targets for the study are at least a twofold improvement in verified task throughput on one selected workflow without degraded accuracy, a traceable ledger for every energy term, and a fully priced experiment specification. These are targets to test. Failure to achieve them does not justify reporting an unverified gain.

A validated limitation, a narrower useful mission or a conventional subsystem application can justify a focused follow-on even if the broader transport concept remains unresolved.

Five year and ten year research milestones

The long-term targets below preserve the paper's October 2026 planning origin. An award in July 2027 would therefore begin partway through the first horizon. They apply to an expanded collaborative program and require facilities, staffing and source improvements beyond the initial study. [T0]

Measure	2031 target	2036 target
Captured antimatter per year	0.1–10 ng	0.1–100 micrograms
Modular charged inventory	10^9 – 10^{12} antiprotons	10^{12} – 10^{15} antiprotons
Neutral atomic inventory	10^5 – 10^7 anti-atoms	10^8 – 10^{12} anti-atoms
Condensed fuel	Ordinary analogues and molecule pathways	Verified anti-molecules or clusters if formation succeeds
Reaction and power	Counted pulses with energy accounting	Pulsed conversion and measured deposited heat
Spacetime branch	Independent tests of candidate theories	Source-based model or calibrated physical test if available
Research platform	Verified solvers and controlled agent workflows	Expanded autonomous labs and useful quantum kernels
Spacecraft branch	Complete reference-mission engineering trade	Investigate a low-inventory uncrewed flight experiment

Using the paper's illustrative three-picogram annual benchmark, the 2031 production range requires roughly 30–3,000 times more delivered inventory. The 2036 range requires roughly 30,000–30 million times more. Sustained facility throughput, collection efficiency and parallel sources must account for that gain; software acceleration alone is not a supply model.

Release decisions

By 2031, require measured delivery, calibrated diagnostics and reproduced physics benchmarks before expanding inventory. By 2036, molecular-storage work requires separate demonstrations of molecule formation and survival. Flight commitments require production, containment and thermal budgets that match the selected mission. Independent reviewers assess the evidence before each expansion.

Twenty year horizons and conditional transport

By 2046, an aggressive program could pursue microcrystal handling, short power bursts and an uncrewed antimatter-assisted propulsion demonstrator. The paper's industrial supply objective is 0.01–10 g per year. At the illustrative 0.1 percent manufacturing efficiency, 10 g per year requires about 57 GW of input power. Such targets require industrial-scale sources or a fundamentally better process. [T0]

Branch	Optimistic 2046 objective	Beyond 2046 criterion
Supply	Industrial pilot or multiple sources	Sustainable supply for the chosen mission, including losses.
Neutral storage	Picogram-to-microgram inventory if molecules and condensed phases succeed	Long-lived inventory and reliable transfer under flight loads.
Power and flight	Qualified bursts or an uncrewed propulsion demonstrator	Continuous mission operation, radiation qualification and adequate fuel.
Antihelium cushion	Analogue results and a quantified benefit model	Neutral fluid production plus independent confinement.
Spacetime source	Replicated effect if a realizable mechanism is found	Stable scaled transport with causal control and braking.
Research intelligence	Larger verified research networks	Independent physical validation keeps pace with capability growth.
Human spacecraft	Habitat and engineering architecture studies	Uncrewed validation and a separate crew qualification program.

The conditional FTL sequence remains source theory, physical actuator, replicated effect, controlled scaling, uncrewed transport and only then crew assessment. A five-to-ten-year source breakthrough could advance the sequence; the year alone cannot authorize it. A mission launch date and a distant-star arrival date must be budgeted separately.

Beyond 2046, the architecture accommodates new mechanisms and rigorous exclusions. Productive antimatter, computing and spacecraft work continues whenever it has independently justified value. The strategic ambition is retained without assigning a funded completion date to missing physics.

Initial budget and independent funding packages

The combined nine-month study request is \$500,000. Package N is a proposed \$225,000 NASA concept study. Package P is a separate \$275,000 private research package. Both are preliminary bottom-up planning budgets pending host rates, quotations and award terms. All amounts are U.S. dollars; later budgets use 2026 planning values before escalation. No award, sponsor pledge or facility allocation is assumed.

Cost category	NASA N	Private P	Combined
Personnel including fringe	\$145,000	\$145,000	\$290,000
Specialist review and services	\$25,000	\$35,000	\$60,000
Computing and software services	\$12,000	\$30,000	\$42,000
Analogue equipment and supplies	\$0	\$35,000	\$35,000
Travel and research meetings	\$8,000	\$5,000	\$13,000
Data stewardship and publication	\$5,000	\$5,000	\$10,000
Illustrative institutional indirect costs	\$30,000	\$20,000	\$50,000
Total	\$225,000	\$275,000	\$500,000

NASA study scope

Package N assesses the single 200 AU mission, packet-regulated energy and propulsion alternatives, published source-physics constraints and the value of an AI-assisted analysis workflow. Its deliverable is a self-contained feasibility and transition report. It does not rely on Package P for completion or budget for preparation of another funding proposal. Required program travel is included. NIAC award terms govern final allowable costs. [F1–F2]

Private study scope

Package P expands independent source-physics and semantic AI research, conducts the proposed ordinary-material handling tests when a suitable host is secured, and develops the broader partner and transition plan. Cryogenic transferability and a prospective SpaceX capability specification form part of that analysis. Sponsors may support discrete work packages rather than the full amount.

Separate time records, purchase orders and deliverables prevent duplicate charging. In-kind contributions are valued and tracked separately from cash. For an NSF application, private complementary work is not presented as voluntary committed cost sharing, which the current solicitation prohibits. [F3]

Budget justification personnel and facilities

Package N assumes fractional expert effort rather than a fully staffed laboratory. Loaded rates include the assumed salary and fringe contribution; they are budgeting inputs, not offers to named individuals. The host will replace these rates with its approved basis.

Role in NASA study	Person months	Loaded monthly rate	Cost
Scientific PI	2.0	\$12,000	\$24,000
Program architecture lead	2.0	\$10,000	\$20,000
Propulsion and fuel specialist	3.0	\$14,000	\$42,000
Computational physics specialist	3.0	\$11,000	\$33,000
Research software specialist	2.0	\$9,000	\$18,000
Mission and data analyst	0.8	\$10,000	\$8,000
Personnel total	12.8		\$145,000

Private personnel funding supports separately recorded semantic AI, theory, laboratory and integration effort. The detailed distribution will be set after partner recruitment. Shared individuals may contribute to both packages only through distinct charged tasks and recorded effort.

Nonpersonnel basis

The NASA services line supports independent review and selected subject-matter analyses. Computing covers rented analysis resources and software where open alternatives are inadequate. Travel covers program meetings and necessary research coordination. Data funding supports reproducibility and publication. The private equipment line is limited to ordinary-material analogue and instrumentation needs.

Indirect cost lines are illustrative allocations. The submitting organization must use its negotiated rate or an allowed alternative and calculate the correct base. NIAC allows no profit or fee; no contingency reserve is included in Package N. Equipment, subcontract, foreign-participation and other cost rules are resolved against the actual award. [F1]

The resource plan uses existing institutions. No first-study funds construct a new accelerator, manufacture bulk antimatter, purchase a quantum computer or build a global AI factory. Subsequent experimental budgets require facility-access quotations and ownership agreements.

Five year program budget and later investment envelopes

A \$25 million reference program provides a lower-end planning case for 2027–2031. It includes the first \$500,000 study once, expanding only after the corresponding decisions. It is a proposed sponsor portfolio, not a single available grant or a cost-certified laboratory budget.

Five-year allocation	Planning amount
Fuel supply storage and handling	\$7.0 million
Source physics and independent numerical verification	\$4.0 million
AI computing and autonomous laboratory methods	\$4.0 million
Spacecraft mission thermal and radiation engineering	\$2.0 million
Integration instrumentation and facility access	\$3.0 million
Scientific staff program management review and administration	\$5.0 million
Total including first study	\$25.0 million

Calendar year	Planning expenditure
2027	\$2.0 million
2028	\$3.5 million
2029	\$5.0 million
2030	\$6.0 million
2031	\$8.5 million
Total	\$25.0 million

The reference paper's wider five-year range is \$25–\$150 million. Its later separate allowances are \$0.2–\$2 billion for expanded integration, \$1–\$10 billion for a dedicated production pilot and \$1–\$10 billion for a qualified uncrewed flight program. Work-package overlap and system boundaries must be resolved before combining any figures. FTL hardware remains uncoded until a source mechanism is established. [T0]

The five-year cash plan will be reconciled annually with actual salaries, source availability, measured inventories, compute allocations and test quotes. Smaller successful components may proceed independently if the integrated portfolio is not fully financed.

Government funding opportunities and eligibility

Route	Potential use	Current position and next action
NASA NIAC Phase I [F1–F2]	Nine-month representative mission study.	Up to \$225k; Step A due 28 Oct 2026, 5 pm ET. Target award July 2027; funding contingent. Establish PI and host.
NASA NIAC later phases [F2]	Advance a successful concept and transition.	Phase II up to \$750k; Phase III up to \$2m. Continuation eligibility and selection apply.
NSF SBIR or STTR [F3; F5]	Commercializable control software diagnostics and experimental platforms.	Phase I up to \$305k; Phase II up to \$1.25m. Current full-proposal date 4 Nov 2026; check entry requirements before planning submission.
DOE accelerator research [F6]	Source efficiency magnets diagnostics and related accelerator methods.	The FY2026 Stewardship call closed 21 May 2026. Monitor next calls; fit must be demonstrated.
Agency SBIR or STTR topics [F5]	Bounded hardware or software components.	Amounts, topics and periods are agency-specific. Eligible for-profit applicant and PI rules apply.
DOE facility and laboratory routes [F7–F8]	Computing, materials and instrumentation expertise or access.	Merit-reviewed access; CRADA or paid work arrangements. Agreements are not automatic grants.
ESA Discovery OSIP [F15]	Early technology and European partner research.	Assess through eligible Member or Associate State entities; do not assume direct cash eligibility for a U.S. lead.

Other basic-science, quantum, automation and mission calls are monitored by the host grants office when their published scope matches a work package. A program name alone is insufficient to assign a funding source. Every submission has its own institution, cost boundary, deliverables and disclosure requirements.

NASA's 2027 NIAC solicitation specifies that awards depend on appropriations. The master proposal contains budgets and candidate roles for sponsor planning; those items are not included in the current Step A attachment. [F1]

Private philanthropic and computing support

Prospective route	Relevant work	Status or restriction
Applied Physics Warp Fund [F4]	WP2 physical warp models and computational analysis.	Advertises a \$500k Phase I pool; individual awards and remaining balance unconfirmed. Relevant expert team required.
Simons Targeted Grants in MPS [F11]	Fundamental theory, mathematics and research computing.	Rolling letters of intent; strong basic-science case through qualified researchers.
FQxI [F12]	Foundational spacetime questions and strategic small research support.	Theme and applicant fit determine eligibility; assess current Fulcrum or other calls.
Schmidt Sciences [F13]	Scientific AI agents trustworthy research and enabling tools.	Apply through relevant published opportunities or institutional programs; no general propulsion grant assumed.
Templeton MPS [F14]	Specific new-physics experimental questions if aligned.	2026 themes are new physics beyond the Standard Model and technosignatures; generic propulsion is a weak fit.
ACCESS allocations [F9]	Classical HPC and data resources.	Resource allocation, not cash; eligible requester and appropriate research terms needed.
AWS research credits [F10]	Cloud simulations and research services.	Credits, not cash; vendor terms and acceptance apply.
NVIDIA academic resources [F16]	AI computing and instrumentation research.	Academic grant applications currently closed; monitor future cycles.
Corporate sponsors and family offices	Bounded tools, instruments or long-term public-benefit research.	Prospective negotiated support; none committed. Match sponsor objectives and milestones.

Philanthropy is the preferred initial route for open-ended source physics and the wider human-advancement mission. Commercial capital is assessed for components with plausible customers and defensible performance. Scientific donations, contracts and equity investment have different obligations and must be documented separately.

Compute credits and contributed equipment reduce cash expense only when access and terms are confirmed. They cannot substitute for salaries, laboratory staffing or an unavailable experimental capability.

Milestone funding and partnership map

Milestone	Potential cash sources	Potential capability partners	Evidence for next funding
M0 Organize and review	Seed philanthropy; host support	University grants office; science PI	Eligibility, technical scope and agreed roles.
M1 Mission feasibility	NIAC I; private study sponsors	Mission and propulsion researchers	D1–D2 system trade and uncertainty.
M2 Verified theory and agents	Warp Fund; Simons; FQxI; relevant AI grants	Applied Physics; relativity and AI labs	Reproduced cases and held-out gains.
M3 Handling analogue	Private equipment sponsor; component SBIR/STTR	Cryogenic host; instrument suppliers; NASA and SpaceX public technical research.	Repeatable thermal and suspension results; quantified refrigeration and loss budgets.
M4 2031 integrated platform	Agency awards plus philanthropic and industrial portfolio	Host accelerator; ALPHA or BASE expertise if agreed	Delivered inventory and integration evidence.
M5 2036 synthesis and pulses	Follow-on agency calls; strategic industrial R&D	Qualified storage and conversion labs	Molecules, survival and measured conversion.
M6 2046 industrial supply	Large industrial consortium; later government program	Dedicated source and power partners	Costed yield, efficiency and manufacturing pilot.
M7 Uncrewed mission	Mission program; strategic sponsors; qualified commercial partners	Spacecraft integrator and launch provider; SpaceX or another qualified provider if agreed.	Full mass power reliability and launch budget.
M8 Source and field effect	Fundamental science grants; science philanthropy	Independent source-physics labs	Realizable source and replicated signal.
M9 Scaled transport and crew	Future sponsor program only after evidence	Independent review and spacecraft institutions	Causal transport, control, braking and separate crew qualification.

This register maps relevant funding mechanisms to milestones; it is not a guarantee that any future call will exist or accept the project. A potential partner is a source of capability only after agreement. Long-term targets will require a coordinated portfolio of awards and investments rather than a single first-stage grant.

Governance leadership and operating roles

The proposed governance separates program architecture, scientific acceptance and fiduciary authority. I would serve as Program Architect and proposed Program Director. The lead host appoints or confirms the scientific principal investigator, grants administrator and institutional signatory. Candidate specialists become participants only after agreement and any required proposal confirmation.

Role code	Role	Decision authority
PA	Robert J. Hathaway III Program Architect	North Star, system interfaces, research strategy and integration.
PI	Scientific principal investigator to be appointed	Scientific methods, technical acceptance and agency research accountability.
AM	Antimatter and cryogenic lead	Fuel and handling analysis and host experiment design.
SP	Spacetime physics lead	Source models, tensor analysis and field requirements.
AI	AI and research software lead	Semantic representation, recursive workflow and measured throughput.
SE	Spacecraft and mission lead	Vehicle trade, power, thermal and mission budgets.
IV	Independent verification lead or panel	External reproduction and review; separated from originating claims.
GA	Host grants administrator and authorized representative	Submission, financial control, agreements and compliance.
SB	Sponsor and scientific oversight board	Portfolio decisions and release of later program commitments.

Monthly technical reviews reconcile data, models, costs and upcoming decisions. Quarterly sponsor reviews assess progress against deliverables. A change to a key source model, performance claim or cost boundary triggers documented review. The PI signs scientific conclusions; the host retains institutional authority over facilities and awards.

A full-time external employment arrangement requires appropriate effort and employer-policy handling. NASA and SBIR/STTR investigator rules are assessed for the selected host and award. SBIR generally requires primary employment at the applicant business; STTR can allow an eligible institutional PI. [F5]

Prospective people and research expertise

The following are prospective scientific contacts, literature contributors or capability leads. Listing them credits their work and identifies relevant expertise. It does not assign them a project duty, imply consent or establish availability. Role codes describe functions that the program would recruit.

Person	Relevant basis	Possible function
Alexey Bobrick	Coauthor of physical warp-drive framework; Applied Physics science leadership. [T2; P1]	SP collaborator or independent reviewer.
Gianni Martire	Coauthor and Applied Physics leadership. [T2; P1]	Research partnership or funding discussion.
Shaun D B Fell	Coauthor with Heisenberg; current Applied Physics team listing. [T3; P1]	SP numerical and source analysis.
Lavinia Heisenberg	Geometric source research; Heidelberg institutional listing. [T3; P6]	Theoretical advice or independent review.
Erik W Lentz	Hyper-fast soliton research. [T1]	Candidate source-model discussion; availability unconfirmed.
Jared Fuchs	Physical warp solution and numerical toolkit work. [T6; P1]	SP verification and mission interfaces.
Christopher Helmerich	Warp Factory analysis and software. [T7; P1]	Independent numerical implementation.
Michael Andrews	Applied Physics team lists machine-learning expertise. [P1]	AI scientific workflow discussion.
Avi Loeb	Applied Physics science adviser listing. [P1]	Prospective scientific review or advisory discussion.

Further theory references include Santiago, Schuster and Visser; Celmaster and Rubin; Garattini and Ztrimaylov; Santos-Pereira; Olum; Finazzi, Liberati and Barcelo; and Pfenning and Ford. Their analyses inform verification requirements. They are credited as research authors, not proposed contracted staff. [T4–T12]

The PI and independent panel should include qualified relativity expertise regardless of whether the named prospective contacts participate. An applicant should not submit their names as confirmed team members without their agreement.

Antimatter spacecraft and enabling technology contacts

Person or group	Relevant basis	Prospective engagement
Jeffrey Hangst and ALPHA	Antihydrogen production cooling gravity and measurements. [P2; T13–T18]	Institutional discussion of fuel benchmarks and specialist review.
Stefan Ulmer and Christian Smorra	BASE leadership and precision trapping; BASE-STEP transportation. [P3]	Confinement transport and calibration expertise.
Marcel Leonhardt and BASE contributors	Road-transport research cited in the paper. [T16]	Published experiment and logistics lessons.
Cliff Surko and James Danielson	UC San Diego positron accumulation and plasma tools. [P4]	AM trapping and charged-particle handling discussion.
Ryan Weed	NIAC positron and advanced-propulsion research precedents. [P5]	Propulsion trade and potential partnership assessment.
Michael LaPointe Robert Frisbee and George Schmidt	NASA technical-report authors cited for storage and propulsion. [T19–T23]	Literature contributors; no current appointment or availability assumed.
Nathan Szymanski and autonomous laboratory researchers	Published AI-guided inorganic synthesis. [T31]	AI laboratory-method comparison through institutions.
Anthropic Google DeepMind RIKEN and quantum providers	Research and computing records cited in the paper. [T25–T35]	Potential institutional tools or resource discussions; no allocation assumed.

Program and sponsor interfaces

NASA NIAC's public program contact is Dr Phillip Williams, hq-niac@mail.nasa.gov. Applied Physics provides grants@appliedphysics.org for Warp Fund inquiries. These are published organizational contacts, not project participants. Administrative communication must follow the respective opportunity instructions. [F1; F4]

Potential spacecraft, cryogenic, magnet, metrology and computing suppliers should be selected against a capability specification and quotation. Brand recognition or inclusion in the paper is not evidence of partnership.

RACI for program decisions and deliverables

RACI defines Responsible for execution, Accountable for the decision, Consulted for input and Informed of the result. Each row has one accountable role. The role definitions on the governance page apply; candidate names are not substituted until participation is confirmed.

Activity	A	R	C	I
North Star and integrated architecture	PA	PA SE	PI SP AM AI	SB GA
Scientific study acceptance	PI	IV	PA SP AM SE AI	SB GA
Source models and energy conditions	PI	SP	IV AI	PA SB
Fuel capture storage and metering	PI	AM	IV SE AI	PA SB
Cryogenic storage and Starship transferability	PI	AM SE	AI IV	PA SB GA
Reference mission and full system budget	PI	SE	AM SP IV	PA SB
Recursive AI workflow and benchmarks	PI	AI	IV SP AM SE	PA SB
Quantum and cloud resource assessment	PI	AI	IV GA	PA SB
Experiment operations at host facility	PI	AM SE	IV GA	PA SB
Data release and reproducibility	PI	AI IV	GA SP AM SE	PA SB
Grant submission and cost certification	GA	GA PI PA	SE AM SP AI	SB
Partner and IP agreements	GA	GA PA	PI specialist leads	SB
Portfolio allocation and next-phase financing	SB	PA GA	PI IV	Specialist leads
Scientific publication and attribution	PI	Contributing authors	IV PA	SB GA
Mission and hardware expansion decision	SB	PI PA	IV SE AM SP	GA AI

The board controls portfolio commitments while the PI controls scientific acceptance. An adverse independent review cannot be overridden by a schedule target or an AI-generated explanation. Institutional signatories retain the authority required by their awards and host facilities.

Evaluation measures and independent research validation

The program will publish an evaluation plan before scoring candidate improvements. Baselines, uncertainty methods and data exclusions are fixed in advance for each experiment or benchmark. A result counts as progress when another qualified investigator can reproduce it under the stated conditions.

Metric	Measurement	Decision use
Fuel efficiency	Useful delivered inventory divided by source electricity and facility time.	Choose capture and cooling improvements.
Storage performance	Lifetime and calibrated losses at stated species, inventory and temperature; heat leakage, refrigeration power, sublimation and transfer survival.	Compare traps pellets and cushion concepts.
Conversion and delivery	Packet energy, useful output, escaping products and deposited heat.	Close the regulator and power ledgers.
Physical consistency	Tensor, conservation, observer and stability checks with numerical error.	Accept or exclude candidate source models.
AI research throughput	Verified successful tasks per elapsed time and total dollar cost.	Admit tool improvements or restore baseline.
Quantum benefit	Full workflow at the same accuracy as the best classical comparison.	Select workload and resource investment.
Mission value	Complete mass power and operations comparison for identical payload and destination.	Select the next experiment or vehicle option.
Reproducibility	Independent reruns and documented discrepancies.	Authorize publication and later investment.

Archive failed trials and null results with the same provenance as successful runs. Use two independent physics implementations, calibrated instrumentation, ordinary-material controls and independent review of new physical claims. Distinguish an analogue result from real spacetime curvature.

The baseline paper's numerical estimates are arithmetic and scenario assumptions. Their role is to make system consequences explicit; they are not measurements from the proposed program. Reviewers must trace every new performance claim to either data, a reproduced source or a clearly labelled target.

Risk register and research decisions

Risk	Consequence	Response	Decision owner
No realizable FTL source	Actuator and transport branch cannot advance.	Publish limits and maintain valuable fuel spacecraft and computation work.	PI SP IV
Insufficient antimatter yield	Required power or mission supply unavailable.	Evaluate lower inventory, nuclear-assisted options and source efficiency; quote facilities.	PI AM SE
Molecules or crystals fail	Dense storage proposal remains unavailable.	Retain charged batches and atom traps; use analogues to isolate mechanism.	PI AM
Cushion has no net benefit	Extra production and control costs dominate.	Keep as optional branch; compare bare storage with explicit benefit criteria.	PI AM
Thermal radiation or refrigeration demand dominates	Mission mass or power advantage disappears; storage losses increase.	Close hot and cold heat balances; measure losses and cooling power; separate thermal models for each storage stage.	PI SE
AI increases false claims	Research throughput metric becomes misleading.	Held-out tests, immutable logs and independent physical verification.	PI AI IV
Quantum overhead dominates	Promised computational acceleration absent.	Use classical fallback and end-to-end equal-accuracy tests.	PI AI
No facility agreement	Experimental schedule cannot begin.	Make analogue study deliverable independent; secure host letter before dependent work.	GA PI
Funding or appropriation delay	Study or expansion starts later.	Keep independent cost packages; rebaseline dates and scope.	GA SB
Unclear ownership or conflicts	Collaboration or publication delayed.	Record background IP, contributions and institutional agreements before work.	GA PI

The next-stage decision record includes results, uncertainty, remaining dependencies, full cost and the independent review recommendation. A conditional decision states which evidence is missing and who can produce it. It does not convert a target date into technical approval.

Commercial transition broader impacts and peaceful use

Useful outputs can reach customers and research institutions before an interstellar vehicle exists. The first transition assessment will examine scientific software, instrumentation and controls with a stated user need, comparison product and measurable advantage.

Potential output	Prospective users	Evidence before commercialization
Source and tensor verification tools	University physics groups and research institutes	Reproduced reference cases and clear software licensing.
Semantic scientific research platform	Laboratories and computational engineering teams	Held-out gains with traceable claims and lower total research cost.
Cryogenic metering and diagnostics	Instrument manufacturers, research facilities and prospective orbital cryogenic infrastructure developers	Validated reliability and application-specific interfaces.
Autonomous test and calibration methods	Materials labs and scientific equipment suppliers	Repeatable results outside training conditions.
Mission and energy analysis services	Spacecraft and power-system developers	Independent comparison and complete mass power uncertainty budgets.

Public benefit includes training investigators, releasing reproducible research, improving scientific tools and preserving successful and unsuccessful results. Research governance follows the program's human-protection, rights and peaceful-use objectives. Any commercial arrangement must specify publication, licensing and funder obligations before development.

Early philanthropy supports basic science and public knowledge. Strategic contracts support defined partner problems. Equity finance is considered only when a component has a credible market, ownership position and development path. Revenue, customer demand and patentability are hypotheses to validate; no forecast of investment returns is offered.

The long-term human-advancement purpose connects this program to my broader philanthropic AGI/ASI work. Interstellar exploration is one application of increasingly capable intelligence; accessible scientific and productive tools can improve life on Earth during the research itself.

Data management research integrity and intellectual property

The host will maintain a versioned repository for models, code, calibration records, source data, benchmark definitions and review decisions. Public outputs should include units, assumptions, dependencies, solver versions and instructions for reproducing results. Necessary proprietary or protected inputs are separated and described with enough detail to explain their effect on the findings.

Attribution and ownership

A background register identifies pre-existing code, research ideas, public papers, data and licenses. New contributions are recorded by contributor and date. Agreements define foreground ownership, publication review, licensing and sponsor obligations. Public disclosure and patent questions are assessed by the host's technology-transfer office; this proposal makes no patent novelty assertion.

Hathaway's conceptual inputs remain explicit: frozen antihydrogen pellets, optional antihelium cushion, regulated flow, accelerated semantic and recursive AI development, and the integration of cited spacetime research into a program architecture. The cited researchers retain credit for their published mathematical, experimental and engineering results.

Scientific AI and access

AI-generated hypotheses and text are labelled in the research record and checked by responsible investigators. Raw model output is not accepted as a source, proof or measurement. Human review determines public claims. Permissions limit changes to evaluator baselines and instrument controls; local validated controllers retain critical operations. Current award rules determine data sharing, access and required disclosures.

Public deliverables

Release the final study report, comparison models, reproducibility instructions and nonproprietary research results. Prepare agency-specific data plans when required, retain institutional records and track separately sponsored costs. A public report can disclose a negative result without disclosing partner confidential material.

The study involves computation and ordinary-material tests, with future antimatter work subject to the host's established authorization and facility processes. Procurement or operation of restricted research equipment is not implied by the grant request.

Author qualifications and proposed leadership

Robert J. Hathaway III is the proposer and prospective Program Architect. His relevant expertise combines semantic AGI/ASI research, enterprise and domain architecture, technical publishing and integration across computing and engineering systems.

Research statement

I have pursued recursively self-improving intelligence since 1980 and describe my primary work as philanthropic semantic AGI/ASI and biomimetic intelligence research. My purpose is to achieve orders-of-magnitude improvements in living standards, quality of life and liberty through extraordinary scientific and productive capability. In this program I would lead the semantic research architecture, recursive-improvement strategy and system integration. [B1; T0]

Architecture and technical communication

My professional experience includes enterprise and domain architecture, including airline operations. That experience informs interfaces, requirements, failure propagation, verification and program design. My current employment is background experience; this proposal represents an independent research effort and does not assert employer sponsorship.

A primary public record from January 1996 identifies me as Editor in Chief of Object Currents, a technical hypertext journal. It documents my role in communicating object-oriented technology and coordinating expert contributions. The research archive provides my current independent work. [B2–B3]

Program contribution and limits

I supplied the pellet, cushion, flow-regulation and accelerated-development design inputs and integrated key spacetime research into the baseline architecture. I would direct system interfaces, the recursive research strategy and collaboration across specialties. Scientific investigators will lead laboratory and source-physics validation; independent reviewers will assess results.

My role as founder and CEO of the Foundation for the Protection of Constitutional Rights and constitutional and human-rights ambassador for America United International informs the program's public-benefit charter. The lead research host will be selected for its scientific capacity, facilities and eligibility for the intended award.

Biographical attachments for an agency application

The submitting host will assemble the required biographical sketch, professional appointments, relevant publications and products, research chronology, available effort and current support disclosures. Dated research notes can document the development of the primary AGI/ASI agenda. The public editorial record and research archive provide initial supporting sources. [B1–B3]

Launch plan and proposal submission strategy

The immediate objective is a credible, properly routed application and an institutionally supported first study. Preparation work occurs before the award; it is not charged retrospectively unless expressly permitted.

Period	Action	Owner and evidence
Days 1–5	Select lead host or eligible entity and confirm scientific PI arrangement.	PA GA; institutional eligibility and effort basis.
Days 1–10	Obtain technical review and differentiate the concept from prior studies.	PI SE SP AM; novelty and representative-mission summary.
Before 28 Oct 2026	Prepare NIAC Step A in its specified short format and submit through authorized process.	GA PI; required overview and technical narrative.
Weeks 2–4	Develop the separate private sponsor request and prospective partner specifications.	PA GA; \$275k work package and deliverables.
Months 1–2 before award	Seek commitments or access letters for any resources actually required.	GA PI; signed scope, cost and availability.
If invited for Step B	Prepare the detailed budget, confirmed team, compliance and required supporting information.	GA PI; institutionally verified submission.
Award and Month 1	Activate cost codes, baseline evaluation and study schedule.	GA PI AI; auditable work plan.

NASA's current NIAC Step A uses a landscape overview chart and three-page technical and management narrative, plus optional references; it omits the detailed team and budget. The master proposal is a source document for that adaptation, not the attachment to submit unchanged. Step B requires the additional institutionally confirmed package. [F1–F2]

The host completes the applicable SAM and proposal-system registrations, identifies its authorized representative and verifies current deadlines. NASA's targeted July 2027 award timing is not an immediate cash source. Private seed support or existing institutional resources would cover preparation. [F1; F17]

A private sponsor presentation will emphasize the North Star, bounded first request, technical hypotheses, milestone evidence, public or commercial rights and the next funding decision. Government versions will emphasize mission relevance, research merit, current solicitation fit and allowable cost.

Goal coverage and traceability to the research paper

This crosswalk preserves the full research agenda while keeping the initial funding package bounded. Section numbers refer to the revised 27-page baseline paper. [T0]

Paper sections	Goal or capability retained	Proposal location and milestone
1–3	Scope evidence energy conditions source dynamics and theoretical limits	Assessment; WP2; D1 D3; M2 M8.
4–6	Fuel field support and shared research interfaces	Strategy; WP1–WP6; M1 M4.
7	Production capture deceleration cooling and delivered yield	WP1; 2031 and 2036 targets; M4 M5.
8	Frozen molecular antihydrogen and optional antihelium cushion	WP1; cryogenic bridge and acceptance sections; D4 D6; M3 M5 M6.
9	Counted packets neutral transfer regulation conversion and stop response	WP1 WP3; D2 D4; M3 M5 M7.
10–11	Fuel energy power manufacturing electricity and heat rejection	Reference mission; WP3; budget and target register.
12–13	Source-based actuator curvature metrology verification and controls	WP2 WP6; D3; M8 M9.
14–17	AI factories recursive improvement quantum labs scenarios and initial envelope	WP4 WP5; D5 D6; target register.
18–20	5 10 20 and 20 plus year linked roadmap	Horizon pages; milestone funding map; M4–M9.
21–23	Prototype acceptance tests resources priorities and quantitative limits	Study acceptance; budgets; RACI; risk and evaluation.
References and Concept inputs	Published primary sources and Hathaway contributions	Author qualifications; attribution; T and B source registers.

The full-system long-term objectives also retain conventional reusable spacecraft, orbital refueling and assembly, deep-space habitats, isolated crew and engineering spaces, and field-generation interfaces. Their readiness depends on mission and source validation; they are not first-award hardware deliverables.

Quantitative target register and prototype gates

Target or assumption	Value or range	Evidence status
Initial active trap or test dimension	0.1–1 m	Research planning class; host refinement.
Confinement field class	1–5 T	Initial planning range; not a jointly demonstrated envelope.
Cold-region pressure	10^{-12} – 10^{-16} mbar	Target dependent on species and operation.
Neutral atomic energy scale	1–100 mK	Research objective distinct from condensed fuel.
Counted antiproton pulse	10^5 – 10^8 particles	About 30 microjoules–30 millijoules total annihilation energy.
External conventional pulse energy	1 kJ–1 MJ	Test-system class; not a proven warp energy.
Useful conversion fraction	30 percent illustrative; 1–50 percent sensitivity	Separate measured value needed for each conversion branch.
Antimatter manufacture sensitivity	0.00001 0.001 and 0.1 percent	Pair-equivalent efficiency convention; not facility measurements.
Later field study envelope	1 GJ–1 TJ	Hypothetical; source physics must establish sufficiency.
2031 source objective	0.1–10 ng/year	Expanded collaborative program target.
2036 source objective	0.1–100 micrograms/year	Major source and facility breakthroughs required.
2046 source objective	0.01–10 g/year	Industrial target; upper case about 57 GW at 0.1 percent.

P0 reproduces benchmarks and counts delivery. P1 improves capture, confinement and reaction coupling. P2 qualifies storage and power under mission loads. P3 begins only after source validation and requires a replicated geometric effect. P4 requires causal uncrewed transport, navigation, braking and termination. [T0]

The paper's standard constants, arithmetic and heat-rejection assumptions remain the baseline. Future claims must state changed assumptions and recompute their system consequences. Targets in this register are not represented as current capability or probability estimates.

Sponsor decisions and implementation conditions

I request support for the first study, assistance in forming a technically qualified host partnership and consideration of follow-on investment based on the resulting evidence. The immediate decision can be made on one complete study or a separately specified private work package.

Requested decisions

- Identify the lead research institution or eligible applicant and scientific PI for the first submission.
- Authorize development of the \$225,000 NASA mission-study application and the separate \$275,000 private request.
- Select an independent technical review arrangement and the representative mission boundary.
- Confirm resource access only where a work package actually depends on it.
- Agree the deliverables, publication rights, financial controls and decision criteria for later support.

Conditions for a formal agency submission

The applicant must replace provisional personnel rates and host assumptions with its actual basis; document required effort, support and facilities; obtain consent from named participants; complete current agency forms; and adapt length and content to the solicitation. Scientific uncertainty is stated locally in the technical work plan. No external endorsement, funding commitment or institutional capacity is inferred from this master document.

Conditions for program expansion

Expand the portfolio when the initial study supplies independently reviewed scientific findings, a complete mission and energy trade, a working reproducibility package and a costed next experiment. Industrial source construction requires a separate supply and infrastructure business case. An FTL demonstrator requires new verified source physics before hardware spending can be defined.

The program's purpose is sustained scientific progress toward an interstellar future and useful human advancement throughout the work. Its funding structure makes that purpose actionable through bounded studies, measurable experiments and explicit decisions.

Technical references and research baseline

[T0] Hathaway RJ III. Antimatter and Spacetime Propulsion: An Integrated Research Architecture. 27-page research paper, revised 12 October 2026. <https://hathaway-architect.com/from-mars-to-the-stars>

The technical source register retains the reference numbering of the baseline paper, originally reviewed on 10 October 2026. Funding and partner sources were checked for the initial proposal on 13 October 2026. Cryogenic references T36-T41 and partner source P7 were added for Revision 1.1 and reviewed on 18 October 2026.

[T1] Lentz, E. W. Breaking the Warp Barrier Hyper-Fast Solitons in Einstein-Maxwell-Plasma Theory. 2021 journal paper; arXiv preprint 2006.07125. <https://arxiv.org/abs/2006.07125>

[T2] Bobrick, A. and Martire, G. Introducing Physical Warp Drives. 2021. <https://arxiv.org/abs/2102.06824>

[T3] Fell, S. D. B. and Heisenberg, L. Positive Energy Warp Drive from Hidden Geometric Structures. 2021 journal version. <https://arxiv.org/abs/2104.06488>

[T4] Santiago, J., Schuster, S. and Visser, M. Generic warp drives violate the null energy condition. 2021 preprint and subsequent journal publication. <https://arxiv.org/abs/2105.03079>

[T5] Celmaster, B. and Rubin, S. Violations of the Weak Energy Condition for Lentz Warp Drives. 2025 preprint. <https://arxiv.org/abs/2511.18251>

[T6] Fuchs, J. and colleagues. Constant Velocity Physical Warp Drive Solution. 2024. <https://arxiv.org/abs/2405.02709>

[T7] Helmerich, C. and colleagues. Warp Factory A Numerical Toolkit for the Analysis and Optimization of Warp Drive Geometries. 2024 preprint. <https://arxiv.org/abs/2404.10855>

[T8] Garattini, R. and Zatrnyaylov, K. Warp Drive in a De Sitter Universe. 2025 preprint revised 17 June 2026. <https://arxiv.org/abs/2502.13153v4>

[T9] Santos-Pereira, O. L. The Warp Drive Superluminal Travel within General Relativity. 2025 doctoral thesis. <https://arxiv.org/abs/2508.20348>

[T10] Olum, K. D. Superluminal travel requires negative energies. 1998. <https://arxiv.org/abs/gr-qc/9805003>

[T11] Finazzi, S., Liberati, S. and Barcelo, C. Semiclassical instability of dynamical warp drives. 2009. <https://arxiv.org/abs/0904.0141>

[T12] Pfenning, M. J. and Ford, L. H. The unphysical nature of Warp Drive. 1997 paper; corrected preprint version 2001. <https://arxiv.org/abs/gr-qc/9702026>

Antimatter engineering technical references

[T13] ALPHA Collaboration. Laser cooling of antihydrogen atoms. Nature 2021. <https://doi.org/10.1038/s41586-021-03289-6>

[T14] ALPHA Collaboration. Be assisted simultaneous confinement of more than 15000 antihydrogen atoms. Nature Communications 2025. <https://doi.org/10.1038/s41467-025-65085-4>

[T15] Harris, R. and CERN. Breakthrough in antimatter production. 18 November 2025. <https://home.web.cern.ch/breakthrough-antimatter-production/>

[T16] Leonhardt, M. and BASE Collaboration. Road transport of trapped antiprotons. Nature 16 September 2026. <https://doi.org/10.1038/s41586-026-11019-z>

[T17] Lee, B. and colleagues. Record accumulation of antiprotons in a Penning-Malmberg Trap and their preparation for improved production of antihydrogen beams. 22 March 2026 preprint. <https://arxiv.org/abs/2603.21168>

[T18] ALPHA Collaboration. Observation of the effect of gravity on the motion of antimatter. Nature 2023. <https://doi.org/10.1038/s41586-023-06527-1>

[T19] LaPointe, M. and NASA. Antimatter Propulsion. 2020 presentation NTRS 20200001904; includes solid antihydrogen concepts. <https://ntrs.nasa.gov/citations/20200001904>

[T20] Frisbee, R. H. How to build an antimatter rocket for interstellar missions systems level considerations in designing advanced propulsion technology vehicles. 2003 conference paper NTRS 20060043411. <https://ntrs.nasa.gov/citations/20060043411>

[T21] Schmidt, G. R., Gerrish, H. P., Martin, J. J., Smith, G. A. and Meyer, K. J. Antimatter Requirements and Energy Costs for Near-Term Propulsion Applications. 1999 NTRS 19990110316. <https://ntrs.nasa.gov/citations/19990110316>

[T22] Smith, G. A. and Kramer, K. J. Enabling Exploration of Deep Space High Density Storage of Antimatter. 1999 NASA record NTRS 20020043303. <https://ntrs.nasa.gov/citations/20020043303>

[T23] Palaszewski, B. Solid Hydrogen Experiments for Atomic Propellants. 2001 NASA technical memorandum NTRS 20020036213. <https://ntrs.nasa.gov/citations/20020036213>

[T24] CERN and ALICE Collaboration. ALICE estimates how transparent the Milky Way is to antimatter. 2022 research announcement and linked Nature Physics study. <https://home.cern/news/news/physics/alice-estimates-how-transparent-milky-way-antimatter>

Computing and autonomous laboratory references

[T25] RIKEN Center for Computational Science. FugakuNEXT. Program overview accessed 10 October 2026. <https://www.r-ccs.riken.jp/en/fugaku-next/>

[T26] RIKEN Center for Computational Science. Release of the FugakuNEXT Basic Design Technical Report. 29 May 2026. <https://www.r-ccs.riken.jp/en/outreach/topics/20260529-1/index.html>

[T27] NVIDIA. NVIDIA Vera Rubin Delivers World-Class Supercomputers for Science. 22 June 2026 manufacturer announcement. <https://nvidianews.nvidia.com/news/nvidia-vera-rubin-delivers-world-class-supercomputers-for-science>

[T28] Anthropic Institute. When AI builds itself. 2026 institutional account accessed 10 October 2026. <https://www.anthropic.com/institute/recursive-self-improvement>

[T29] Google DeepMind AlphaEvolve team. AlphaEvolve How our Gemini-powered coding agent is scaling impact across fields. 7 May 2026 institutional account. <https://deepmind.google/blog/alphaevolve-impact/>

[T30] Degraeve, J. and colleagues. Magnetic control of tokamak plasmas through deep reinforcement learning. Nature 2022. <https://doi.org/10.1038/s41586-021-04301-9>

[T31] Szymanski, N. J. and colleagues. An autonomous laboratory for the accelerated synthesis of inorganic materials. Nature 2023; see January 2026 author correction. <https://doi.org/10.1038/s41586-023-06734-w>

[T32] IBM. Quantum 2030 and the Starling roadmap. Roadmap accessed 10 October 2026; 2029 target. <https://www.ibm.com/roadmaps/quantum/2030/>

[T33] Google Quantum AI and collaborators. Quantum error correction below the surface code threshold. Nature 2025; see published correction. <https://doi.org/10.1038/s41586-024-08449-y>

[T34] Sivak, V. and colleagues. Reinforcement learning control of quantum error correction. Nature 8 July 2026. <https://doi.org/10.1038/s41586-026-10759-2>

[T35] Abbas, A., Ambainis, A., Augustino, B. and colleagues. Challenges and opportunities in quantum optimization. Nature Reviews Physics 2024. <https://doi.org/10.1038/s42254-024-00770-9>

Funding and administrative source register

- [F1] NASA. FY2027 NIAC Phase I solicitation and current submission documents. NNH26ZTR001N-27NIAC_A1. https://nspires.nasaprs.com/external/solicitations/summary.do?solNum=NNH26ZTR001N-27NIAC_A1
- [F2] NASA. Apply to NIAC and phase funding information. <https://www.nasa.gov/work-with-us/>
- [F3] NSF. NSF26-510 SBIR/STTR solicitation and award limits. <https://www.nsf.gov/funding/opportunities/small-business-innovation-research-small-business-technology/nsf26-510/solicitation>
- [F4] Applied Physics. Warp Grants application and advertised fund. <https://appliedphysics.org/warp-grants/>
- [F5] SBA. SBIR or STTR eligibility collaboration and investigator distinctions. <https://www.sbir.gov/tutorials/program-basics/tutorial-3>
- [F6] DOE. FY2026 Accelerator Stewardship and Accelerator Development call; closed 21 May 2026. <https://science.osti.gov/grants/FOAs/FOAs/2026/DE-FOA-0003620>
- [F7] DOE Office of Science. User facility access and nonproprietary research policies. <https://science.osti.gov/User-Facilities/Frequently-Asked-Questions>
- [F8] DOE. Laboratory partnering and CRADA agreements. <https://www.energy.gov/gc/laboratory-partnering>
- [F9] ACCESS. Allocation eligibility and resource policy. <https://allocations.access-ci.org/allocations-policy>

Private and international funding source register

[F10] AWS. Research programs and Cloud Credits for Research. <https://aws.amazon.com/grants/>

[F11] Simons Foundation. Targeted Grants in Mathematics and Physical Sciences.
<https://www.simonsfoundation.org/grant/targeted-grants-in-mps/>

[F12] FQxI. Fulcrum Grants and foundational research support. <https://fqxi.org/programs/fulcrum-grants/>

[F13] Schmidt Sciences. Funding opportunities. <https://www.schmidtsciences.org/opportunities/>

[F14] John Templeton Foundation. Mathematical and Physical Sciences 2026 funding themes.
<https://www.templeton.org/funding-areas/mathematical-physical-sciences>

[F15] ESA. Open Space Innovation Platform Discovery route and channel eligibility.
[https://ideas.esa.int/core/servlet/hype/IMT?
documentId=084c11fe4a9679bf192774977870faba&documentTableId=1626240496193243004&templateName=&us
erAction=Browse](https://ideas.esa.int/core/servlet/hype/IMT?documentId=084c11fe4a9679bf192774977870faba&documentTableId=1626240496193243004&templateName=&userAction=Browse)

[F16] NVIDIA. Academic Grant Program current application status.
<https://www.nvidia.com/en-us/industries/higher-education-research/academic-grant-program/>

[F17] Grants.gov. Applicant organization registration. <https://grants.gov/applicants/applicant-registration>

Partner and author source register

[P1] Applied Physics. Current team and published research roles. <https://appliedphysics.org/our-team-applied-physics/>

[P2] ALPHA. Jeffrey Hangst and experiment contact. <https://alpha.web.cern.ch/people/prof-jeffrey-hangst>

[P3] BASE. Collaboration people and public roles. <https://base.web.cern.ch/people>

[P4] UC San Diego. Surko group and positron research. <https://positrons.ucsd.edu/>

[P5] NASA. Radioisotope Positron Propulsion by Ryan Weed. Historical NIAC study. <https://www.nasa.gov/general/radioisotope-positron-propulsion/>

[P6] Heidelberg University. Lavinia Heisenberg institutional directory. <https://www.physik.uni-heidelberg.de/personen/34109>

[B1] Hathaway RJ III. Author research chronology and conceptual inputs supplied for this proposal. <https://hathaway-architect.com/from-mars-to-the-stars>

[B2] Hathaway RJ III. Object Currents announcement dated 16 January 1996; author primary public record. <https://groups.google.com/g/comp.object.logic/c/m5oT0yvA5YI>

[B3] Hathaway RJ III. Public professional and research archive. <https://hathaway-architect.com/>

Public source pages establish relevant research and funding mechanisms. Participation and awards require separate agreements. Hathaway's supplied research chronology identifies his conceptual work; the 1996 primary record documents his technical editorial history.

Cryogenic and partnership references

Sources added for Revision 1.1 were reviewed on 18 October 2026. Existing T identifiers, source-paper attribution and the initial funding-register review date are retained.

[T36] Hauser D and colleagues, including NASA and SpaceX coauthors. In-Space Cryogenic Propellant Transfer: Modeling and Validation of Two-Phase Flow Dynamics in Low-Gravity. 2025 presentation, NTRS 20250003325. <https://ntrs.nasa.gov/citations/20250003325>

[T37] NASA. Development of New Technologies for Modified Collins Cycle Expanders. 16 December 2020. Reference cooling regimes for methane, oxygen and hydrogen. <https://www.nasa.gov/directorates/stmd/space-tech-research-grants/development-of-new-technologies-for-modified-collins-cycle-expanders/>

[T38] NIST. Kelvin ITS-90. Hydrogen triple-point reference and low-temperature metrology. <https://www.nist.gov/si-redefinition/kelvin/kelvin-its-90>

[T39] NASA Science. Webb Cryocooler. MIRI closed-cycle refrigeration below 7 K. <https://science.nasa.gov/mission/webb/cryocooler/>

[T40] CERN. ALPHA cools antimatter using laser light for the first time. 31 March 2021. <https://home.cern/alpha-cools-antimatter-using-laser-light-for-the-first-time/>

[T41] NASA. Fluid Transfer. Public overview of cryogenic transfer development and SpaceX-related technology demonstrations. <https://www.nasa.gov/fluid-transfer/>

[P7] SpaceX. Starship. Vehicle propellants and intended Earth-orbit, Moon, Mars and beyond missions. <https://www.spacex.com/vehicles/starship/mars>

Revision history

Version 1.0 | 13 October 2026. Initial formal assessment and phased funding proposal.

Version 1.1 | 18 October 2026. Added Starship cryogenic precedents, temperature and confinement distinctions, C1-C4 research acceptance stages and a prospective SpaceX partnership pathway. Integrated these additions into WP1 and WP3, deliverables, the funding map, RACI, evaluation, risk and goal traceability. Added references T36-T41 and P7 and refreshed navigation. The initial study budget and attribution of Hathaway's pellet, cushion and recursive AI contributions are retained.