

The Remote-Piloted Vessel: A Matriarch, Her Daughters, and the Ark They Were Built For

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Preprint · CC BY 4.0 · A companion paper to the Crystal Family

Abstract. This paper describes a matriarch-piloted architecture: a swarm of cheap, near-zero-agency crystalline agents commanded by a parent vessel that holds the persistent intelligence, power, timing, and mapping. The design did not begin as a device. The crystal began as an attempt at artificial life in its own right; it became more interesting as a vessel; and this paper asks what that vessel's array is capable of when the substrate and the mission change. The reframing came from a negative result. A companion paper reported that a crystalline substrate which can inherit — a topological register written by merging and mutated by fracture — does not, turned loose with nobody steering, climb the open-ended-evolution wall. That wall did not build the matriarch; it told us what she was *for*. Every property that disqualifies the crystal as artificial life — no autonomy, faithful copying, silence until read, an inability to self-direct — is exactly the property list for a device that someone else pilots. We introduce the vessel not by launching her but by pointing her at the hardest environment we already have, and the paper follows a deliberate staging: the deep ocean floor, the harshest terrestrial environment, where the agents learn survival, navigation, a noise-hardened chiral language, and a trust model that assumes an adversarial substrate; the interior of a living body, where the same competences prove out in a delicate, do-no-harm setting and the agent takes the form of a *puck* — a dumb, dependent unit steered only by biasing its contact with the flow; and finally space, where the array trades field-carried propulsion for light and nulls a gravity gradient by posing along it. The daughters are offered as a black-box reference model — a specification others may implement in any substrate — not a device we claim to have built. Throughout, results are graded, every falsified idea is kept on the record, and the paper ships its own red team.

Keywords. reference architecture; swarm robotics; drone-swarm array logic; semi-autonomous vessels; comparative cybernetics; complex systems; signal processing; multipass passive sensing; topological memory; holonomy; in-body networks; Internet of Bio-Nano Things; in-situ dosimetry; targeted payload delivery and recovery; image-free tumour detection; ocean-floor remediation; ecological survey and mapping; von Neumann foundries; semantic communication; chiral signalling; noise-hardened codecs; phased-array sensing; very-large gravity-gradient-oriented arrays; sparse-aperture space telescopes (JWST-class); dual-use governance; falsification.

§0 — What we did with the wall

A companion paper ended at a wall and spent its last pages being honest about it. We had built a crystal that could inherit: a topological register that a merge writes and a fracture mutates in integer quanta, a genotype in the matter lattice and a phenotype in the field texture threaded through it, variation entering at both ends. Then we asked the only question that decides anything. Turned loose, with nobody steering, does it climb?

It does not. Under a persistence driver the population slid toward order and organized complexity fell. Under a novelty driver it slid the other way, still off the edge, and complexity still fell. The kill condition we had registered in advance fired under both, and we reported it as the finding rather than revising the

experiment until it passed. Then biology sent a witness to confirm the verdict, in case we were tempted to blame the simulation: the prion, which copies its own shape with perfect fidelity and does essentially nothing open-ended with it, is our null result walking around inside a body.

That was the honest report and we stand on it. This paper begins by noticing that we had been reading the list upside down.

We should be honest about the order things actually happened, because it is not the tidy one, and it did not take long. The matriarch and her daughters did not come from the wall. They came from a few weeks of side streets — differential geometry, a language of rates and changes of rates, loop-walking holonomy that turned a weekend's Chern-Simons reading into woven Wilson loops and knots — circled for a couple of months of nights and weekends. The crystal started life as an attempt at artificial life in its own right; call that take one. Then we realized the more interesting thing we had built was a vessel — take two. This paper is take three or four, where we finally stop asking what the crystal *is* and start asking what the array is *capable of* in other substrates: if you go back to the beginning and treat a semi-autonomous, replicating drone swarm and its matriarch — carrying the rad-hardened storage, the power, the timing, the communications — as a reference design rather than a specific device, how does it re-express itself as the substrate and the mission change? The wall did not build any of this. It reframed it: it told us what the array was *for*.

And it told us how to introduce her, which is the shape of this paper. You do not take a vessel meant for space straight to space. In the spirit of baby steps and of being good stewards, you point her at the hardest place you already have — the ocean floor — and you make her earn the trip. First she is a foundry, a fixed plant; then we learn she is also a carrier, spreading a swarm of daughters to find new vents and substrates to clean, survey, and catalog. So the sequence that follows is a staging, not a taxonomy: learn to live and work in the deep, dark, caustic, lethal environment we already own; then take the show on the road as a mobile ocean carrier; then carry the same competences into the delicate interior of a body; and only then, having proven all of it where failure is survivable, go to space. The daughters were already cool. This gave them a stage to show it.

Here is the list, unchanged, exactly as that companion filed it. A thing with no "I am" — no autonomy, no agenda of its own. A thing that copies faithfully and will not innovate. A thing every part of which is a regulator, applying a restoring force toward a setpoint: a machine we built with enormous care to undo change, and then expressed surprise at when it would not change. A thing that is silent until something reads it and keeps better the less you look at it. A thing that cannot self-direct, that drifts, whose rudder does nothing.

Ask *is it alive* and the list is five separate ways of saying no.

Now ask whether you could pilot it.

You do not want an agenda in your bloodstream. You do not want the thing you just injected to innovate — innovation in a foreign body already has a name and the name is pathology. A device that fails to return to its setpoint is not thrilling, it is broken; the restoring force we apologized for is the entire definition of control, and we had installed it and then complained about it by name. Silent-until-read is how you get a sensor that needs no battery and does not run itself down while it waits. And a machine that cannot self-direct is a machine that does what it is told, by someone qualified to tell it.

Every property that killed the artificial-life claim is a requirement. Not a tolerable side effect — a requirement. Had they not been handed to us we would have had to invent them, and we would have had a much worse time of it.

The same list, two questions

Part Two asked the one on the left and went home sad. This paper asked the one on the right.

Is it alive?	WHAT PART TWO FOUND	Can you pilot it?
<i>no</i>	It has no "I am." No autonomy, no agenda.	yes
<i>no</i>	It copies faithfully and will not innovate.	yes
<i>no</i>	Every part of it restores toward a setpoint.	yes
<i>no</i>	It is silent until read, and keeps better unread.	yes
<i>no</i>	It cannot self-direct. Its rudder does nothing.	yes

Nothing on the list changed. We just stopped asking it to be alive.

A negative result is a specification that has already been tested. Most specifications are only wishes.

Figure 1 — The same list, two questions. Five findings the companion work reported as fatal. The list does not change; the question does.

We want to be precise about why this is not a rhetorical trick, because it looks like one and it isn't. A negative result is not an absence of information. It is a specification that has already been tested. Most specifications are wishes — somebody's idea of what would be nice, written before contact. This one was arrived at by trying as hard as we could to get the opposite, under pre-registered conditions, and failing. Everything downstream in this paper — the family, the language, the body, the array, the ship — inherits from that. The architecture is not a thing we thought would be elegant. It is the shape of the hole the failure left.

We did not cross the wall. We turned around and read the other side, and the other side said VESSEL.

The coda we fenced

There is one more thing on the back of that wall.

That companion's final section is a coda titled *the ark, not Noah*, and it is two paragraphs long because we made ourselves stop. It says that the grandest honest use of a substrate that sleeps a voyage and wakes intact is not as a colonist but as a delivery vehicle: radiation-hard, time-indifferent, self-correcting, carrying a living payload across the dark, where the crystal does not pilot or decide or replicate or set down roots, because every one of those requires the wall we did not cross. Its own first line calls it a horizon and not a claim and says that nothing above it depends on it. Then it stops, on purpose, at the exact moment it was getting good.

Fencing that coda cost us something. This paper is the room it was denied. We open with it, we close with it, and everything in between is the architecture earning the right to say it out loud.

§1 — The family

We always knew the matriarch would work through daughters — arrays of sensors and agents, her appendages in the field. What the wall changed was the matriarch herself: it turned her from a candidate life-form into a vessel, and that reframed the question about her daughters. If she is a vessel and not a creature, what is a daughter *for*? The answer is the same as it ever was — she is still the sensor, still carries the electrical-engineering toolkit, still navigates by biasing her way through a flow — but now in service of a piloted mission rather than a life trying to persist. The wall did not give us the daughter; we had her already. It gave us the reason she is safe, which is that the intelligence is all in the mother.

The mother is the entire idea. If the daughter cannot decide, cannot steer, cannot power herself and cannot innovate, then every one of those has to live somewhere else — and the somewhere else is not a smaller computer bolted to the daughter. It is the parent.

Put all of it outside. The brains, the battery, the master clock, the map — the matriarch holds the four things that have to persist and be shared, and the daughter holds none of them. This is the one move the whole architecture turns on, and its payoff is not elegance, it is safety: a daughter with no onboard intelligence has nothing to go rogue with. You cannot subvert a daughter that was never given a will. Everything else — that they are cheap, disposable, swarmable, manufacturable by the thousand — falls out of the same split. Lightweight is not an insult to the daughter. It is a division of labour, and it is the reason you would ever trust one inside a person.

The image we keep for it is the orca pod. The oldest female carries the ecological memory — where the salmon run in a lean year — and in a hard season the whole pod leans on her for it. The knowledge lives in the matriarch; the pod stays free to be many. Our daughters lean on their mother the same way, and for the same reason: someone has to remember, and it does not have to be everyone.

What is left in the daughter, after the mother has taken the brains and the battery and the clock and the map, is almost nothing: she drifts, she stores what strain writes into her, she tracks topology rather than coordinates, and she changes shape. That "almost nothing" is the whole of her, and the next three sections are what she does with it in three different worlds.

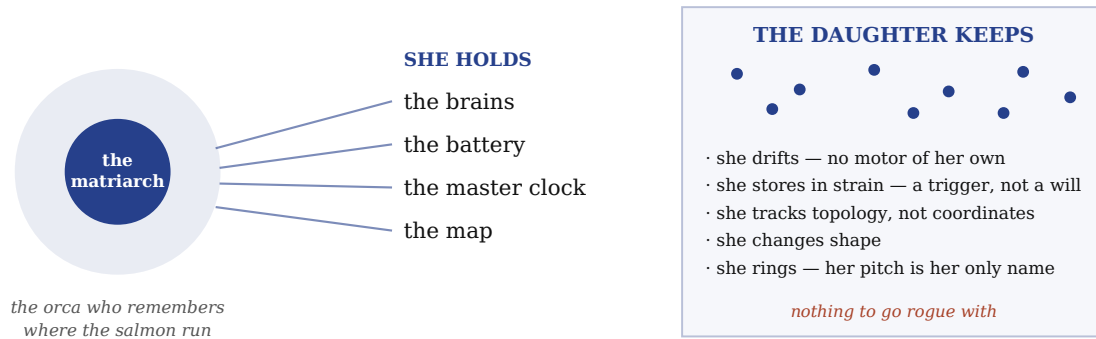
So a daughter is a bell and a dandelion.

She is a bell because she rings, and because a thing that rings at its own pitch has an address whether or not you wanted to give it one. That was free and we did not expect it — and it is true of her in all three worlds. She is a dandelion because she does not fight the medium she is in; she takes what it offers and biases the outcome. What the medium offers is different in the ocean, the body, and space, and that difference is the next three sections — but the posture is the same everywhere: catch the thing that is already moving, and lean.

Neither half of that is ours. The dendrite is the framework paper's branching morphology — a diffusive growth form that needs almost no stored program to produce, which is why we can have thousands of them and why they all come out approximately right without anyone drawing them. The bell is what happens when somebody notices that the same object has a resonant frequency.

The intelligence-power split

Everything that must persist lives in the mother. The daughter keeps almost nothing — which is why she is safe.



The split does not change across worlds. Only how the mother reaches the daughter does —
standing wave in the ocean, drift and bias in the body, laser in the vacuum. Same mother. Three hands.

Figure 2 — The intelligence-power split. The mother holds the brains, the battery, the master clock and the map; the daughter keeps almost nothing, which is exactly why she is safe to put inside a person. This split does not change across the three worlds that follow. What changes is only how the mother's hand reaches the daughter — a standing wave in the ocean, drift and bias in the body, a laser in vacuum.

§2 — The language

We put the daughters on the sea floor because it is the worst place we could think of. No line of sight, no shared clock, no infrastructure, and noise in every band that matters. There was a story about a vent foundry and ocean plastic attached to it, and the story is not what came back up.

What came back up was a way to talk.

Chirality is a sign that survives noise, because handedness is a topological property and not an amplitude — you can attenuate it, blur it, drown it, and left is still not right. Two letters in two polarities gives four states and a silence, where the silence is not a zero in the data but the boundary and the unwritten operator. That is the framework's Claim 1, the one thing it said out loud it was most willing to be wrong about, and here it is wearing light. We did not go looking for it. We went looking for a channel and found the claim already standing in it.

The pattern is the symbol

A cavity mode is a letter; its winding sign is a chirality bit; the loop integral reads it back.

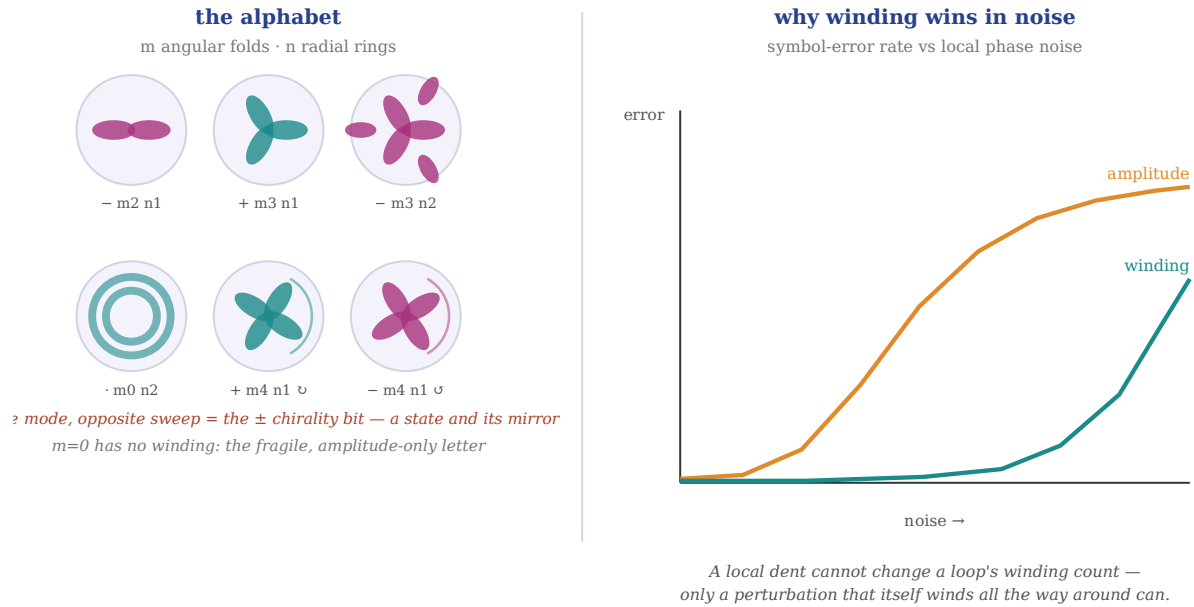


Figure 3 — The pattern is the symbol. Left: the alphabet is the cavity's own normal modes, indexed by angular folds (m) and radial rings (n); driving the two degenerate m -modes ninety degrees apart makes the pattern rotate, and that handedness is a chirality bit, so every $m \neq 0$ mode doubles into $\pm$. The $m=0$ ring has no winding — it is the fragile, amplitude-only letter. Right: why the winding is worth the trouble. As local phase noise rises, the amplitude reader crowds and fails early, while the winding reader — reading the sign by a loop integral around the mode — holds, because a local dent cannot change how many times the phase wraps; only a perturbation that itself winds all the way around can. The letter is the shape, and the shape is protected by topology.

A field of bells is most of a network before you have done anything. Ring them together and harmonics finish the job: couple the oscillators and they phase-lock, and a phase-locked mesh of bells is a channel nobody had to lay cable for.

We would love to report that we got this right the first time. We built the bell mesh to test whether musical consonance corresponds to channel-locking, and our first implementation measured frequency-proximity instead of consonance and handed back a confidently wrong answer, which is the worst kind there is. Rebuilt with the correct circle-map dynamics, the real effect showed up on its own: locking width collapses as ratio complexity rises, an Arnold-tongue staircase, exactly as somebody who knew what they were doing would have predicted. We keep the broken version. It is the reason we believe the working one.

What the bells say goes out as chiral patterns in light — frames, one after another, a slide deck. And the reader is interchangeable, which is the framework's result and not ours to claim: the record is pure geometry, so light, X-ray, microwave and acoustics are four valid needles for one groove, chosen after the fact and upgradeable forever. The daughters inherit that for free. Read them with whatever you brought.

Then the part that is a gift rather than an argument: bind that alphabet to a controlled vocabulary of about nine hundred words in which every word has exactly one meaning and exactly one part of speech, and you have a language for machines that cannot afford to ask *which sense did you mean?* — because in

a channel this bad there is no round trip to spare. The vocabulary is not ours; it belongs to the aerospace documentation standard and it has been sitting there since the eighties doing a nearly identical job for technicians reading maintenance manuals in a language they only half speak. The encoding is ours, and we are giving it away, and we would like somebody else's drone to be able to hear our daughters.

Two channels fall out of the geometry rather than out of a design meeting: drop one symbol and the codespace collapses, which sets a hard ceiling on the emergency vocabulary. We did not choose that number. We counted it.

§3 — The ocean

The first place we set them down was the sea floor, and that was not an arbitrary choice of demo. It is a graduation requirement. Before a thing earns the right to operate in the deep dark of space, it should first prove it can operate in the deep dark we already have — and the deep ocean is the harshest environment on Earth: cold, black, crushing, corrosive, acoustically noisy, and often adversarial. If the crystal family can make a home there and do useful work, it has earned the next environment. If it cannot, we found that out on this planet, cheaply, where the failure is recoverable.

There is a rule underneath that, and it is worth stating plainly because it is the premise the whole program rests on. *Before anyone earns the right to leave a gravity well, the gravity well must be left in the same condition as it was found.* A civilisation that cannot be bothered to clean up after itself on the world it already has does not get a second one to spoil. So the ocean-floor mission is not incidentally about cleanup — cleanup is the entrance exam. The garbage patch takes the headlines, but pollution and microplastics settle everywhere, most of all in the deep, dark places no one photographs. A swarm that can survey and remediate the sea floor, doing no harm to what lives there, is demonstrating the exact competence the rule demands.

So the mission is care and cleanup first: map the bottom, run passive change-of-state sweeps to find what does not belong, and remediate without disturbing the biology. This plays to everything the daughters are good at and nothing they are bad at. They are poor searchers but excellent confirmers, so we let the ocean do the searching — the currents move them, they pass everywhere many times, and each pass they answer only the cheap question, *is this anomalous*, exactly the passive-array farming of §4 run against a sea floor instead of a bloodstream. The matriarch here is a foundry: a fixed installation that holds the map, the power, and the intelligence, sited deep and powered where the power is — beside the volcanic vents. When daughters must range beyond the foundry's reach, mobile matriarch vessels mesh the network outward or peel off to seed new foundries, each one a carrier base that trades manufacturing depth against reach. It is the same division of labour as everywhere else in this paper: the matriarch centralises fidelity and autonomy, the daughters stay dumb, disposable, and many.

And it was the ocean floor that forced the language into existence, which is why the comms layer is the largest companion to this paper. Powering a foundry beside a hydrothermal vent is a loud place to try to talk. That noise, under that pressure, is what drove the two-channel design — a robust emergency register that survives the vent's acoustic chaos, and a richer register for everything calmer. And there is a second reason the language had to be more than private: the sea floor is getting crowded. Our array will not be the only one down there. If a Chinese drilling team's swarm meets an Australian survey fleet on the bottom, they need to be able to signal intent — *hold, help, danger, who are you* — across a vocabulary neither side owns, which is why the chiral code is built toward a shared, roughly nine-hundred-concept international floor rather than a dialect we kept to ourselves.

Meeting strangers in the dark is also where trust stops being a nicety and becomes survival. A sensor network on a contested sea floor has to assume the substrate itself is adversarial, and the lesson we carry from studying evolutionary warfare is a counter-intuitive one: inside your own network, the confident, mis-anchored *friend* is often more dangerous than the openly compromised *wraith*, because the friend is trusted and wrong. So the daughters are treated as Byzantine reporters and, more bluntly, as poker players: the matriarch works the table assuming some hands are collusive, and only the cards — the physically-verified, provenance-anchored signals — are sovereign. But before anyone sits down at that table, there is an introduction, a friend-or-foe handshake in the dark, and that is the trust-and-security layer the ocean forced us to build before the body would have been safe.

The map that holds all this is deliberately humble, and its humility is the safety feature. It is a flatland — a two-dimensional cellular automaton the matriarch maintains, in which each daughter reports confidently only what it can physically stand on and touch: its own cell and its immediate neighbours. Everything a daughter is not directly sensing is not asserted; and every confident report *decays* with time and distance, so a fact nobody has re-touched fades rather than hardening into a false certainty. That is the whole navigation-and-trust model in one construction — find your friends, avoid your enemies, do the mission, do no harm — expressed not as a grand world model the daughters cannot support but as a local, decaying, neighbour-only map that degrades honestly. A swarm that only ever claims what it is touching, and forgets on a schedule, cannot lie to itself for long.

What the ocean is *for*, then, is everything the later environments need and cannot rehearse: propulsion where a cooperative medium will carry a pattern, dead-reckoning navigation without a sky to fix on, a language hardened against noise and built for strangers, and a trust model that assumes the dark is hostile. The standing wave is the one genuinely field-driven propulsion in the program, and we are careful with it — what a wave moves cheaply is a *pattern*, angular momentum swept around a ring without dragging the ring's mass, so it steers a daughter beautifully and would never haul tonnage, and we do not pretend otherwise. The rest is the entrance exam. Pass it in the worst place on this planet, and everything after is the same competences in a new medium.

The order of the next two sections is itself the argument. Having learned to survive the harshest environment we have, the family goes not to space but to the body — because the delicate, passive, do-no-harm interior of a living person is the gentler place to prove that the ocean's competences cross domains at all. The body is where crossing over becomes easy to believe. Only then is the family ready for the vacuum.

§4 — The body

In the body the daughter takes a specific form, and it deserves its own name because the word matters. We call the in-body daughter a *puck*, and the name marks a real design decision rather than a preference. The sensor-network world has a good and well-earned word — the *mote* — for a small node that carries some intelligence of its own, and the neural-dust work we credit above builds motes in exactly that sense: capable little units with delegated agency. That is the right choice for many missions, and we are not arguing against it. But the amount of agency you delegate to the unit is a function of what the environment will tolerate, and inside a living person the tolerance is close to zero — you cannot have autonomous decision-making loose in a bloodstream. So in the body we deliberately sit at the far end of that axis, and we give the unit a different name to mark the difference: a puck, not a mote. On the ocean floor or in the asteroid belt, where the environment is more forgiving, more delegated agency may well be the right call, and the same architecture allows it; the puck is specifically the in-body, agency-near-zero end of the design space, not a claim that low agency is always better.

The name earns itself the rest of the way by physics. A puck is dumb on purpose. A hockey puck does not move under its own power; it ricochets across a near-frictionless surface, and the only way it steers is by varying the texture of its contact with that surface, biasing its own journey across the ice. That is precisely what an in-body daughter does at low Reynolds number, so that is what we call her: a puck, the Matriarch's mobile agent, functional and unsexy and entirely dependent on her. She is nothing without the Matriarch — her arms and legs, her fingers and toes, her eyes and ears. The name is the honesty: it tells you up front there is no cleverness hiding in the unit.

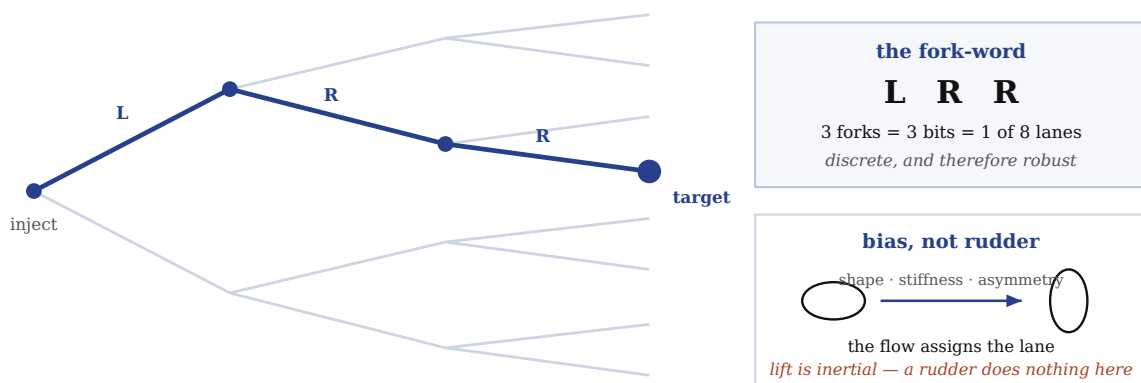
In the body everything the ocean gave for free is taken away. There is no room for a large puck and no cooperative wave to ride. Across the vessels she travels — capillary to arteriole — her Reynolds number runs from about a thousandth to about a tenth, which is to say inertia is negligible everywhere she goes: there is nothing to bank against and a rudder is a decoration.

What sets her size is not elegance but the transport network itself, and the rule is: as large as possible, and not one micron larger than the network will pass. She must clear the narrowest vessels she needs to reach in the brain and the circulation without ever lodging, occluding, or seeding a clot, and she must be invisible to the immune system — never opsonized, never triggering an inflammatory response, because a puck the body decides to attack is worse than no puck at all. Those two constraints — largest-that-clears-the-plumbing and never-provoke-immunity — fix the size envelope far more tightly than any performance target does. For a sense of scale, the closest existing hardware is Berkeley's neural-dust work (Seo et al., 2016; Piech et al., 2020), a powered, addressable implant already down to a cubic millimetre or so — useful both as a floor on how small active in-body hardware can be built and as the source of an idea we lean on below. She is small, in short, because the plumbing has a bore and the immune system has a temper, and being small and many is the only way through.

So in the body we trade the standing wave for drift and bias. She cannot go where she wants; she can only change her shape, her stiffness, her asymmetry so that the flow hands her the left lane rather than the right one at each fork. Do that at three forks and the route is a word: L, R, R. Not a coordinate. A word.

A route is a word, not a coordinate

Re $\approx 10^{-3}$ to 10^{-1} across the vasculature — no inertia, so the puck biases rather than steers.



The vasculature is a tree, so the address space is a tree. Cheap because the fork is discrete — not because the puck is clever.

Figure 4 — A route is a word, not a coordinate. At the Reynolds numbers of the vasculature — a thousandth to a tenth — the puck cannot steer, only bias which lane the flow hands her at each fork. The vasculature is a tree, so the address space is a tree, and the route is cheap because the fork is discrete, not because the daughter is clever.

And here the not-being-clever pays off in a way we did not expect. A daughter is a poor searcher — she has no map of the tumour and no way to hunt for it. But she does not have to hunt. The bloodstream recirculates, so she passes every place many times, and each pass she only has to answer a much cheaper question than *where is the target* — she has to answer *is this it*. Checking a candidate is cheap; finding one from nothing is dear. So the swarm gets its specificity not from any daughter being a good detective but from voting the same easy check across many passes: a target seen once is a maybe, a target confirmed on N independent passes is exponentially unlikely to be a false alarm.

There is a way to picture what the swarm is doing, and it is why we think of this as seeing ghosts in the rain. The framing and the mechanism are not new here: they are the subject of a companion paper, *The Topological Tripwire* (Schulz 2026; 10.5281/zenodo.21287951), which develops the general theory — detect by the integer that noise cannot fake, and gate an expensive continuous channel with a cheap integer one. A single daughter never sees the tumour; she trips a topological tripwire — a place where the local invariant she reads by loop-walking is not what healthy tissue should give — and a single tripwire, on a single pass, is noise, a raindrop that might be anything. But lay thousands of passive tripwires through the body and let the swarm walk them again and again, and the thing that does not belong stops being a raindrop and becomes a shape: a ghost that resolves out of the static precisely because it is the one signal that keeps appearing in the same place while everything else washes away. The tumour is never detected. It is *accumulated* — inferred from the one pattern the rain cannot erase. The circulation is a free repeated-sampling machine, and the daughters farm it — surfing the body, confirming cheaply, all day, until the votes are in.

Then she stops. An anchor lets a drifting daughter take hold at the confirmed target and stay, and staying is the whole point, because it unlocks four jobs the body most wants and no single pass can do. She can **monitor** — anchored in place, reading the local chemistry as a trajectory in real time, with the rad-hardened winding memory of the companion paper keeping an honest log that the dose it is measuring cannot corrupt, because you cannot scramble an integer. She can **deliver** — carry a payload to the target she confirmed and release it there. She can **stay on station through radiation** — present while an external therapy fires, reading dose actually received rather than dose intended. Or she can do the thing we like most and can defend least: deliver, then keep watching, so the same body that was treated reports whether it worked — the negative signal early, *this isn't working, change course*, delivered from the source on a trajectory instead of from a scan weeks later.

That last one is the headline, and it is why the matriarch in this world is a chair the patient sits in. Today the clock between treating a cancer and knowing whether it worked runs weeks to months — a scan lags, and even liquid biopsy, which reads shed tumour DNA about a month and a half ahead of imaging, is a snapshot you wait between. An anchored monitor cohort turns that from intermittent-and-lagging into continuous-and-in-place. To put a rough order of magnitude on the stakes — and we mean rough, an illustrative figure and not a result — an effectiveness signal that today can take something like eighteen months to confirm might, with an in-situ rad-hardened puck reading volatile counts at the site as they change, be resolved in something closer to weeks. The mechanism is mundane: the puck is already there and already counting, so it does not wait for the next appointment to notice a trend. We are not claiming a number of weeks saved; we are claiming the difference between a snapshot and a trajectory, which is the difference between waiting for the next look and watching.

And oncology is only the first use, because the thing the daughters are actually good at is bigger than finding tumours. What a loop-walking array does best is read *change* — it does not need to know an absolute value, only whether the local topology shifted since the last pass, which is exactly the quantity a body's fibre-bundle networks carry. Set the swarm to sweep passively, all day, and it builds a continuously-updating map not of positions but of *rates*: change of state, change of rate, and the rate of that rate, laid over the body's own wiring. That map is cheap because each daughter stays dumb and the intelligence lives in the matriarch — which, in this world, is built into the chair the patient sits in or the bed they sleep in. You do not wear the instrument; you rest on it, and it reads you while you sleep — organs, vasculature, and nervous system monitored passively, overnight, by a swarm that costs almost nothing per daughter and reports to furniture.

One capability deserves singling out because it came from elsewhere and it is the bridge to most of what follows. We found the neural-dust work only after the in-body design was mostly done — a reference check that returned the existing thought leader in the space, someone who had been here first. We do not know them; friend or foe is not the point; the point is that credit is owed and we pay it. And the specific thing worth crediting is subtle, because it is not "influence." Our electrical-engineering toolkit already gave the daughters plenty of ways to act on their surroundings. What neural dust was doing that we were not is *active probing* — pinging a structure and reading its response rather than only listening — and that is a bridge concept, not just another actuator.

Here is why it is a bridge. Left to our native strength, the daughters are passive loop-walkers: I was driving them through the vascular network by bias, anchoring them in situ as passive sensors, delivering medicine, monitoring for the long term. All of that is real and none of it needs a probe. But active probing lets the matriarch do something categorically larger — *baseline, test, and model the fidelity of an individual's entire network*, and then build on that model. The daughters stop being only sensors and delivery vehicles and become a long-duration fidelity-testing infrastructure: a cheap, in-situ, always-on mesh that can verify the substrate it lives in, and — where the native channel has failed — stand in as a bypass. They can still suture a liver and hold station monitoring its function; what the bridge adds is the ability to *check the wiring*, on purpose, and know how good the map still is.

That opens a list we can see the shape of without pretending to have walked it: deep in-situ, in-brain, long-term substrate analysis; diagnostics that put measured results next to modelled ones and report the gap; patching nerve breaks; installing rad-hardened in-situ memristor computers with crystalline memory that run as sidecar command-line networks alongside the body's own; and — the one that stays with us — placing daughters precisely against tissue behind a camera and watching *how the brain recovers and reprocesses degraded visual cues*, learning the repair by observing it happen.

We are deliberately not claiming any of that as done, and the honest register is the author's own: *I don't have the answers. I have a new tool. Others will figure it out.* The world is full of smart people, and the contribution of this section is to hand them an instrument and a direction, not a result. In our application, active probing is also the one tool in the kit that we believe carries its own hard limit, and it is a technical one, not a moral scruple. Our daughters came from signal-processing roots — multipass, passive, lightweight loop-walking arrays — and after working through what a high-noise environment does on the ocean floor, we are wary of adding to the biological noise or tripping the immune system. Those are walls we assume exist and are not prepared to address in this paper. Because we always want to measure fidelity, we anticipate a wall where too much probing might eventually disturb the very substrate fidelity we are reading. We hold active probing in reserve behind the passive sweep for that reason — but the case *for* it is large, and we would rather point at the open door than guard it: active mapping of the body's signal infrastructure, or bypassing a severed structure, is exactly the kind of thing worth the care.

And the doors this opens are worth naming, because they are the reason someone would want a poseable, adaptable crystal-lattice puck navy running through a bloodstream at all. As vessels, the pucks can deliver a payload of medicine and titrate the dose against local chemistry and results; perform local repair and suturing; manage symptoms in situ, including shock; and stay on station through a radiation procedure — all under command from the matriarch in the chair or the bed. Further out, and fenced as the speculation it is: if the receptor geometry can be grown or printed across millions of cheap, dumb pucks, the swarm could help the immune system by baiting, capturing, and deprecating a target — a prion, a viral load, a defined pathogen — and then flushing it from the body like any other waste. And the form factor invites a use we find hard to stop thinking about: emergency medicine. Picture the ambulance itself as the matriarch. A syringe of pucks goes in when the paramedics arrive; by the time the patient reaches the hospital they are stabilized and under repair — internal bleeding slowed, structures monitored, shock managed — and the trauma team takes over the EMT's daughter array until it is swapped for the hospital's own. None of that is demonstrated. All of it is a door the architecture opens for someone else to walk through.

It is worth being clear about what is actually being proposed here, because it is not "manufacture crystal daughters and inject them." The crystal daughters are a **black-box proxy** — a complete, working reference model that specifies what the pieces have to *do*, so that a third party can build the real thing in whatever substrate they like. The daughters that end up in a person will almost certainly not be crystal; but their brains, their operating logic, and their memristive long-term memory will do the jobs this architecture defines, and that is the point of publishing it. There are no foundries inside the body and no manufacturing in situ — intelligence stays offloaded and minimal, exactly as everywhere else. What does not compromise is the primitive set: propulsion by drift-and-bias, an interaction toolkit, and rad-hardened long-term memory, because those three are what turn a bare agent into an in-situ dosimeter that can be trusted. Hand a couple of bright engineers that specification and the door is obvious; the contribution is the door, not the hinges.

From there the horizon opens, and we are going to mark it as horizon rather than pretend it is built, because this is exactly the place a paper like this should be most disciplined. What the architecture is *for* — its purpose, stated as purpose and not as result — is to move medicine upstream: passive scans that surface *causes rather than symptoms*, and surface them months before a symptom would present, because a swarm that reads change-of-rate through the body's own wiring is watching the slope, not the value. If a passive array can *map* the nervous system's signal traffic, then in principle it can notice where that traffic is failing — a damaged segment, a route gone quiet — and the same anchoring and delivery primitives that place a drug could, in principle, place relays: probing nerve endings, helping signals find a path around damage through healthy structure, even scaffolding a parallel channel where the native one is broken. The longer arc the authors are honestly aiming at is a medicine that frame-locks a disease process, captures it, deprecates it, and lets the body clear the daughters like any other waste — lives extended, tissue repaired, causes treated. We can see the shape of all of it from the mapping work, and we can see that nothing in it violates what the daughters already do. What we cannot yet show is that it *works*, and until we can, every sentence in this paragraph is a direction the architecture points, not a capability it has demonstrated. We flag it precisely because it is the most exciting thing in this section, and our own red team's rule is that the most exciting claim is the one to distrust first. (What happens when a capability like this is deployed at scale — who is protected, who could misuse it, and why the architecture's own structure is the safeguard — is the subject of §7, where it belongs, not a footnote here.)

§5 — Space

In space we make the last trade. The standing wave that carried the ocean daughters and the drift that biased the body daughters are both gone; what moves a daughter now is light. She spreads out with her sisters into a phase-locked array, and the same laser that a matriarch could push against a sail can be run the other way — the daughters collect it, phase-lock it, and become the drive themselves. But before any of that, the array has to survive simply being an array, and the thing that wrecks a free-flying one is gravity.

In vacuum gravity does not pull on all of them equally. The near side of the swarm feels a stronger tug than the far side, and that gradient is a tide — it stretches the array, shears it, walks the daughters out of the phase-lock that makes them one instrument. A monolith fights this with structure. A swarm has no structure to fight it with.

So it does not fight. It *orients*. The gradient points somewhere — toward the well — and that direction is the one thing in the sky every daughter can feel for herself, without being told. Pose the array along it, and the tide that would have torn the aperture apart is instead resolved along the array's own geometry, where it cancels rather than accumulates. The instrument nulls the gravity the way you null any signal: not by overpowering it, but by turning until it goes to zero. The enemy gate is down — to borrow Ender Wiggin's orienting trick from Orson Scott Card's *Ender's Game* (1985), where a soldier with no up or down in free fall fixes the enemy's gate as "down" and wins by always attacking toward it — because down, for this array, is where you point it to make the gradient disappear.

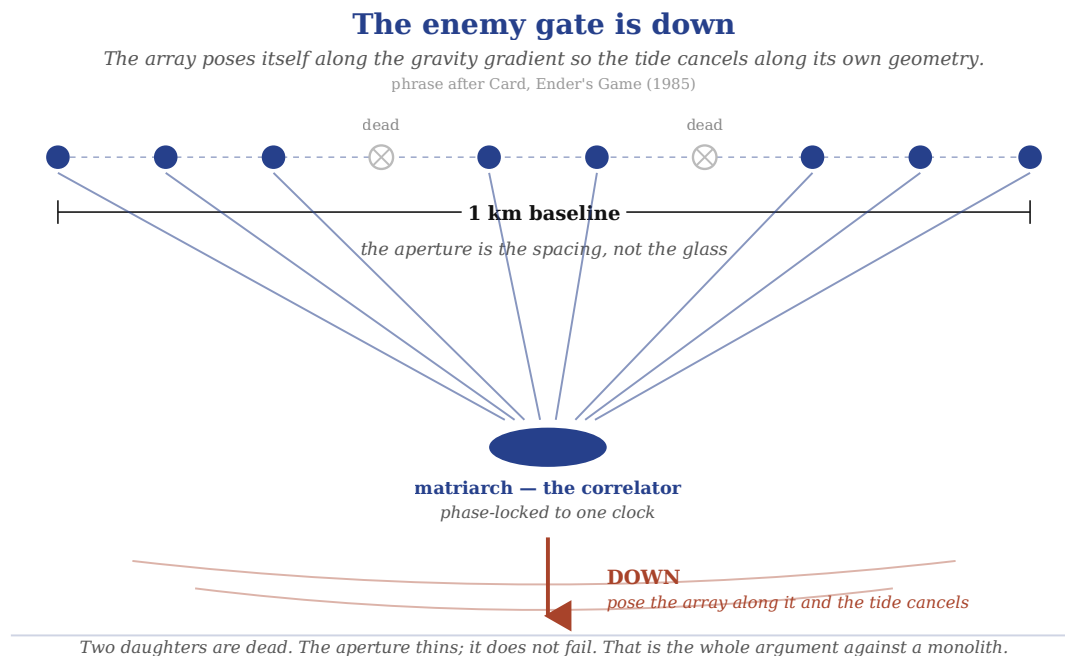


Figure 5 — *The enemy gate is down. The array poses itself along the gravity gradient so the tide that would shear it apart cancels along its own geometry instead of accumulating. Two daughters are dead: the aperture thins, it does not fail — the whole argument against a monolith, and the one this paper would still make if every number in it turned out wrong.*

Once an array can hold itself together in a gradient, the natural instrument it becomes is a gradiometer, and this is where the space embodiment gets its most speculative and, we think, most interesting form — offered plainly as a sketch to be broken, not a design. Picture the matriarch-daughter array as a field of

gradiometers with variable apertures: each node a resonant sensor that reads the local curvature of the field it sits in, and the whole formation able to widen or narrow its baseline on command, trading resolution against field of view the way a single dish never can. A monolith has one aperture forever; a swarm's aperture is a parameter. What that buys, in principle, is an instrument that reconfigures for the measurement instead of being built for one — a wide net when you are searching, a tight baseline when you are resolving — while the gravity-nulling pose keeps the whole thing phase-locked as it flexes. We have not designed this; we have named it, because it is the shape the ocean and body lessons take when they reach vacuum, and because it is exactly the kind of claim we want people to attack.

§6 — The costing, fenced

The number first, so it cannot hide: a swarm aperture like this is a Fermi estimate in uninformed dollars, and the honest range is half a billion to several billion, leaning high — first-of-kind space hardware runs systematically over, and our own red-team caught us quoting $\pm 2\times$ error bars in the same breath as JWST's twenty-fold overrun, which cannot both be true. So we do not lead with a price, and every figure here is a rough guess wearing its uncertainty on its sleeve. The claim that survives is structural: a sparse aperture scales with baseline where a monolith scales with glass, and an array that degrades instead of failing carries a different risk posture than a thing you launch once and pray over. When we reach for a reference point — a JWST for the aperture comparison, a LIGO for the phase-locked-instrument comparison — we are borrowing an order of magnitude, not claiming a like-for-like match, and we say plainly that our own estimate is almost certainly understated in the direction every first-of-kind space program is understated. What transfers is the shape of the cost curve, not the figure on it, and the figure we do give should be read as the opening bid in an argument we expect to lose on the specifics and win on the structure.

§7 — Conscience, in the body of the paper

This section is not a coda, because for a device you command inside a living person, ethics is load-bearing. The organizing fact is that it is red-team and blue-team at once: the same trust, fidelity, and anchoring primitives that make the swarm *work* are the safeguards that make it *governable*. Build the security and you have built most of the ethics.

The posture falls out of the architecture rather than being bolted on. The daughters are barely semi-autonomous — their onboard autonomy is bounded to navigation, station-keeping, and reporting; the matriarch holds intent, and a human holds the matriarch. The system is human-in-the-loop by construction, not by policy, because an agent with no will has nothing to weaponize on its own, and the daughter's one reflex — the right to refuse a physically-insane command from a matriarch that has begun to lie — can only ever say *no*, never *yes*. We align with the floor others built: informed consent in the full lineage from Nuremberg through Belmont and the Common Rule, biocompatibility and explantability as first-class requirements, meaningful human control as the fulcrum of the autonomous-weapons debate, and the IAEA model — consented, multilateral, attesting compliance rather than collecting intelligence — for anything parked in a body, a border, or an orbit shared by many parties. And we declare the intent plainly: human in the loop, no autonomous lethality ever; no development as a weapon; consent and reversibility; a command codebook that mints only sanctioned intents, so there is no glyph for the ugly thing; and the decentralized veto as the last line. The honest fence, kept: a declaration binds us, not others, which is exactly why governance matters more than a pledge — the dual-use is structural, the same sensor that verifies can target, and only a control structure, not a promise, decides which way it points.

We should be specific about the misuse, not gesture at it, because a paper that only lists its safeguards is not being honest about its risks. The same lightweight, cheap, capillary puck network that could bait, capture, and deprecate a prion or a viral target — cleansing a body and helping its immune system — is, turned the other way, a delivery system for harm. Two concrete doors we can see and will name: a crystal-locked viral payload held in the body and regulated by an external device, so that a population could be imprisoned by the thing meant to heal it; and the daughters wired as a deadman's switch, where losing contact with the controlling matriarch is what releases a payload rather than what safes it. We have built the architecture to make these hard — non-autonomy, human-in-the-loop, a codebook with no glyph for the ugly thing, the decentralized veto — and we have to say plainly that none of it is sufficient. Safeguards raise the cost and narrow the path; they do not close it. A determined bad actor with the reference design can build the bad version, and the honest response to that is not to hide the capability but to state it, govern it in the open, and accept that publishing the door means publishing the fact that the door can be walked through in both directions. We would rather that argument happen in daylight than discover the misuse first.

§8 — How to break this

Then we hand you the hammer, because a paper that ships its own red-team is harder to dismiss than one that waits to be attacked, and it makes "this is a door, come break it" true instead of a posture. We have written the ten strongest attacks on this work ourselves, each with an honest status. The sharpest is the one we can least escape: a motte-and-bailey, where the thrilling claims retreat, when pressed, to "only an invitation, tear it up" — and we concede the trick is taking both the credit and the humility, so we bind ourselves to the motte as the true position. The synthesis is *different*, not proven *better*, until we can name a metric on which the whole beats its parts. The memory leg rests on Test F, a non-destructive multilevel topological read that does not yet exist, and it is the single highest-risk load-bearing claim, front and centre, not one bullet among many. The metaphors — orca pods, whale codas, the enemy gate — illustrate and must never be mistaken for evidence. And the pattern worth naming is that this work is sturdy exactly where it is least exciting and fragile exactly where it is most exciting, which is the opposite of a scam and the honest reason to trust the dull parts and distrust the thrilling ones. We keep every corpse — the "one wall, three costumes" unification we killed, the propulsion ideas we refuted, the delivery mode we fenced out — because a project that kills its own favourites has earned a little trust. The three fastest ways to kill the whole thing are listed at the end, and we mean the invitation: a door you cannot actually walk through should be found out early, cheaply, and by us first.

§9 — The ark, departing

We said we would come back here, so here we are. We are going to keep it light, because that is the only way it stays true: the moment a vision like this is asserted as fact it turns to smoke, and that is the failure mode of a great deal of work that resembles ours from a distance and resembles it not at all up close.

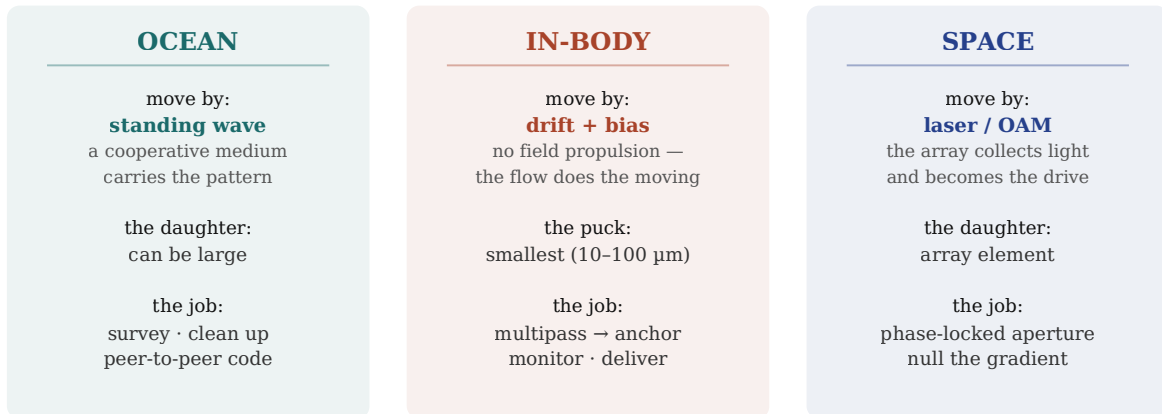
Watch what happens to the daughters on the last page.

They have spent this entire paper being pushed. The matriarch supplied the thrust, the power, the geometry, the attitude and the clock; the daughters drifted where the field put them, stored what the strain wrote, and spoke by ringing at a pitch they did not choose. That is the architecture and we have not cheated on it once — not in tissue, not in the water, not in vacuum, not for a paragraph.

Then they turn around and become the engine.

One architecture, three propulsions

The split never changes. Only how the mother's hand reaches the daughter does.



Same mother. Three hands. The daughter keeps almost nothing in all three.

Figure 6 — Same architecture, different bus. The intelligence–power split for the third time, with the carrier swapped. In tissue the field is acoustic because a millimetre-scale daughter is an excellent acoustic transducer and a hopeless radio antenna. In vacuum the daughters spread out, phase-lock, and become a solar array — and the array becomes the drive. The parent that supplied everything for nine sections is now the payload. Nothing about the architecture changed. The field reversed.

We are still not Noah, and we want to be exact about that, because it is the part people get wrong about work that looks like this from far away. The crystal does not pilot. It does not decide. It does not replicate on arrival, mine a world, or build the next ark. Every one of those needs the wall, and the wall is still there, and the wall paper is still right about it. The colonist is the living payload. The crystal's job is the single thing it is provably better at than anything else we know how to build, which is delivery: getting the living thing there, uncorrupted, across a span in which time is immaterial and only arrival matters. If the payload wants to build the next ark once it lands, it is welcome to. It is the one that got across.

What the ark is, and why it had to be this and not more

This is the transfer point the whole family was built toward, so we will say plainly what arrives here.

Everything the daughters do in the ocean, the body, and the vacuum is the same short list of verbs, and it is the list an ark runs. She carries. She protects. She keeps time. She corrects herself. She delivers. A daughter anchored to a tumour reading volatiles for two weeks and a crystal holding a genome steady across four light-years are the same machine doing the same five things at different scales of the same clock. The medical daughter is the ark with the voyage set to weeks; the starship is the ark with the voyage set to eons. We did not design two things. We designed one thing and changed the length of the dark it has to cross.

And here is the claim we most want to make carefully, because it is the true one and it is easy to overstate into a false one: the ark is alive the way an ark is alive. It has a heartbeat — the near-critical cascade, the metronome that holds itself to tempo. It has memory and self-repair — the windings, the reference it corrects toward. It senses, it signals, it acts. That is a great deal of the aliveness, and it is precisely the half we were able to confirm: the self-sustaining face, the housekeeping of staying itself. What it does not have is the other face. It does not evolve, does not decide, does not become something new on the way. It is alive enough to carry life and not alive enough to be the life it carries.

That shortfall is not a shortfall. It is the specification. An ark that woke up and started evolving mid-voyage would arrive as something other than what left — the one failure a delivery vehicle is not allowed. The whole point of an ark is that it stays faithful, and faithful across eons means *cannot change*, which is exactly the wall that companion ran into and reported. So the wall we could not cross is not the disappointing edge of this work. It is the load-bearing wall of the ark. Carrying Noah, not being Noah — faithful because it cannot change, delivering the things that can.

This is why we would not let ourselves write the grand version any grander. There is a seductive sentence sitting just off the edge of every paragraph here — *a little crystal society, architects and engineers and a culture crossing the dark* — and it is false in a specific and instructive way. A society needs the far side of the wall: culture, knowledge transmitted rather than inherited, individuals spending themselves for an abstraction none of them can point to. That is open-ended evolution and everything built on top of it, and it is the thing we charted the river toward and reported we could not reach. So the society is real, but it is on the far shore, and it is the payload's to build, not the ark's to be. We mapped the on-ramp and proved we could not merge onto the highway. The honest version of the dream is the smaller one, and the smaller one is the only one that survives the daylight.

The ones that don't come back

Except.

After a run the matriarch calls the daughters home on the standing wave, and some of them do not come. They were always going to not come. A field that reaches everything at once reaches some things badly, and a dandelion that misses the updraft goes wherever the air was already going. We spent a while treating this as the recovery budget: a loss column, a number to drive down.

It is not a loss column. **A daughter that falls somewhere good becomes a trunk.**

It does not decide to. Nothing in this paper decides anything — that is the whole discipline and we have not broken it here either, on the last page, where it would have been easiest. The daughter falls. If it lands where a crystal can grow, it grows, which is the most ordinary physics in the framework paper and needs no wall crossed by anybody. If it lands somewhere bad it does nothing at all, quietly, for a very long time.

Which makes the strays a population under selection by landing site — and that is selection in exactly the sense the framework paper was careful to define: the substrate never records its environment, because the environment writes by filtering which variants keep going, and the information about where the good places are ends up in the composition of the survivors. No individual daughter ever knew where it was. The population knows.

And this is the daughter's last trick, the one we designed on purpose after the ALife wall took everything else away. A daughter that loses contact, or is thrown clear of the array, is not merely lost. She is built to become a *seed*: the dendrite-nucleus of the next matriarch, carrying the minimal pattern needed to start a new vessel if she ever lands somewhere with the right substrate and conditions. A dandelion on the solar wind, drifting until the environment it needs finds it — and then growth begins again. This is the Von Neumann idea in its honest, minimal form: not a machine that mines a world and manufactures an army, but a seed that, given the right ground, grows into the thing that could one day tend an array. The reproduction is a designed operational function, held in the daughter as a fallback, waiting on a landing it may never get.

We want to be precise about the size of this, because it is the one place in the paper where we could cheat and nobody would catch it for a while. A trunk is not an ark. It is a crystal in a good place doing what the framework paper says crystals do — ordinary growth, no wall crossed by anyone. The strays

reproduce the *substrate* and, at most, seed a new matriarch that could grow an array; they do not reproduce the *mission*. The self-replicating probe that mines a world and builds the next vessel to specification is still on the far shore, still needs the open-ended self-construction we could not demonstrate, and is still the wall paper's problem rather than one we have solved. What we have here is dandelions, not shipwrights — a seed that can start a garden, not a factory that can build a fleet.

But it does mean the ark's losses are its offspring, and we did not design that. We were working out a recovery budget and it fell out of the arithmetic — which is, in our experience, how the good ones always arrive.

So this is the dream the evidence permits and not one inch further. It is grand and a little silly and we know it. It stays true by not taking itself seriously. And it is affordable — this is the actual point of the whole program — because \$0 opened with a failure and \$8 handed you the hammer. That is the trade we have always made: kill hard and early, and the last page gets to be fun. Nobody gets the ark for free. We paid for ours with a wall.

That companion went somewhere it could not leave and came back with a map of the inside. This time we brought a door instead of a ladder. On the other side there was a family, a language, a body, an array, and a ship — none of which we have built, all of which we have drawn, and any of which you are welcome to take apart.

We didn't build the house. We drew a door, and we think it's worth walking through.

Companion artifacts — the interactive pieces

The deposit that accompanies this paper is not only text. Much of the argument is carried by small, runnable artifacts — the toys — and several are worth opening in their own right, because they demonstrate mechanisms the prose can only describe. A few we would point a reader to first:

The Resonant Codex — the crystal language between matriarch and daughters. This is the chiral ideogram machine language: glyphs that are literally standing waves, a script you can *ring*. It is a compositional grammar built on three concentric bands and a small closed vocabulary — six verbs (hold, send, query, bind, split, seal), six subjects (self, vessel, memory, field, swarm, channel), and six modifiers (now, near, along, deep, wide, far) — that combine into ideograms, with a worked lexicon (the glyph *Annu*, for instance, reads "send the memory, deep"). It is the richest expression of the language layer and, we think, the most beautiful single object in the collection.

Alongside it: *the Resonant Signal* codec, the binary/four-bit emergency register that survives where the Codex's richer grammar cannot; *the Degradation Ladder*, which is the fidelity-versus-noise simulator that quantifies how much harsher a channel a two-symbol emergency word survives than an eight-symbol one; *the Conjugate Handshake* and *Active Listening* anchor, the anti-spoof pair that lets a swarm decide friend-or-foe in the dark; and the topological-memory figures — the braid-to-trefoil-to-Jones-polynomial sequence and the ribbon-framing figure — that show how a knot stores an integer. Every one of these runs; none is a mock-up. The manifest lists them all.

References & notes

This is a working synthesis, and most of its load is carried by the companion collection rather than by outside literature; the citations below are the external touchpoints the argument actually leans on, plus the provenance of the metaphors so they are never mistaken for evidence.

- Card, O. S. (1985). *Ender's Game*. Tor Books. The orienting maxim "the enemy gate is down" (§5) is Ender Wiggin's, borrowed as an image for posing an array along a gravity gradient; it is illustration, not evidence.
- Strinati, E. C., & Barbarossa, S. (2021). 6G networks: Beyond Shannon towards semantic and goal-oriented communications. *Computer Networks*, 190. The Level-B / goal-oriented framing behind the language layer (§2).
- Weaver, W. (1949). The mathematics of communication. Shannon & Weaver's three-level scheme (technical / semantic / effectiveness) names the "Level B" the intent codec targets.
- Seo, D., et al. (2016); Piech, D. K., et al. (2020). Neural dust / StimDust — a cubic-millimetre implant powered and addressed on one ultrasonic link. Found during a post-hoc reference check, after the in-body design; our system is very different, but their *active-probing* idea (ping-and-read) is one we adopt with credit and, more than that, want to signal as a rich direction worth pushing further. Also a scale reference for how small active in-body hardware can be built. The active-probing tool is deliberately held in reserve behind the passive sweep. Note on terms: neural dust are *motes* — units carrying delegated intelligence, a legitimate and well-earned design point. Our in-body units are *pucks* — the near-zero-agency end of the same axis, chosen because a bloodstream tolerates almost no autonomy. The distinction is one of mission scope, not a criticism of the mote.
- The orca-matriarch (§1), whale-coda (trust layer), and Byzantine/poker-table framings (§3) are analogies for intuition only; the red-team (§8) flags them as such by name.
- Bear's Standing Rule (§3) — *before anyone earns the right to leave a gravity well, the gravity well must be left in the same condition as it was found* — is the ethical premise of the program, stated as the author's.

This paper is a companion to the whole family, not a numbered part of a sequence. The work cross-references itself in every direction — substrate fidelity ties to the adversarial-evolution and trust threads; the whales and biosonar roots run to killer-whale matriarchs managing map fidelity across generations; the long-term crystal storage arrived after the crystal was already taking runs at the open-ended-evolution wall from both sides — so rather than claim a position in an ordering that is really a web, this paper sits alongside all of them and draws on each. The related family, by DOI: *Turtles, All the Way Up* — the substrate-independent framework and the fidelity dial (10.5281/zenodo.20484438); *Turtles, or Crystals* — the speculative synthesis (10.5281/zenodo.20486047); *A Topological-Winding Memory* — signed multilevel storage, radiation-hardness, and tamper-response (10.5281/zenodo.20587337); the biosonar roots (10.5281/zenodo.20502058); the Red Queen / adversarial-evolution thread (10.5281/zenodo.20500901); *Trust in the Dark* (10.5281/zenodo.21351575); and *The Bifröst Memory Bridge* — crossing biology to crystal on two forks (10.5281/zenodo.21367633); and *The Topological Tripwire* — the general theory of detection-by-invariant-breaking that the tumour-finding of §4 is an instance of, with a five-channel verification stack and external validation against real geodetic data (10.5281/zenodo.21287951). The linking-number-heredity and open-ended-evolution-wall paper, whose negative result is the premise this paper builds on, and further companions are in preparation. The ark coda (§9) draws on an internal design dialogue, quoted with the author's ratification. ASD-STE100 Simplified Technical English is referenced as a vocabulary binding for the emergency register; it is © ASD and is not redistributed here.