Technical Appendices

Kugelblitz Jettison Mathematics

The complete mathematical record of ARBOUR|05's final approach, drive jettison, and impact event. These numbers are the foundation of the crash history, the power grid document, and the formation of the debris field beneath and around Arbour. When in doubt, return here.

All figures calculated from first principles. Sources: Hawking (1974), Penrose (1965), standard relativistic mechanics.

A Note on Terminology

The Convergence is the entity itself — unknowable, eldritch, existing outside this reality entirely. It does not act with intent in any sense humans can interpret; it does not hold grudges, make plans, or choose targets. It simply *is*, in a way that occasionally presses against the boundary of this universe.

Aetheris is what happens *here* as a result — the phenomenon, the bleed-through, the physical and biological consequences felt in this reality. Aetheris can be measured, mapped, and exposed to. The Convergence cannot. Where this document refers to "Aetheris intensity" or "Aetheris exposure," it means the measurable, in-reality phenomenon. Where it refers to "the Convergence," it means the unknowable source on the other side of the boundary.

Overview

ARBOUR|05's destruction was not a single event. It was a cascade — each failure creating the conditions for the next, compressed into a timeline measured in milliseconds at its fastest and minutes at its longest.

The cascade did not begin with an impersonal containment fault. It began with a man.

Dr. Jian Wei had concealed the extent of his own Aetheris affliction, acquired during the voyage, from everyone aboard ARBOUR|05 — possibly, in its early stages, from himself. By the time the affliction reached the point of compromising his judgment and autonomy, nobody around him

understood what was happening until it was already happening. At the moment containment failure became inevitable, it was Wei who destabilised the Kugelblitz's magnetic containment field.

The engineers had 21 seconds from that point. They used them correctly. That is why anyone survived.

It ended when 4.3 kilotons of antimatter annihilation permanently widened a cluster of the Penumbran Reach's reality tears and scattered ARBOUR|05's wreckage across an unremarkable stretch of Cordis — terrain with no prior significance, no name, nothing to mark it as special before the ship came down. Arbour was built where it crashed, not the other way around.

Part One — The Kugelblitz Drive

What It Was

ARBOUR|05's primary propulsion system was a Kugelblitz — a microscopic black hole formed from ultra-concentrated radiation and maintained in a macro-Penning trap using intense electromagnetic fields. The black hole was kept from evaporating by active feeding of matter and high-energy laser inputs during the voyage, its mass carefully managed to provide controlled Hawking radiation thrust.

The Kugelblitz was the only propulsion system capable of accelerating a vessel of ARBOUR|05's mass to the relativistic speeds required for a journey to KOI-8565 within a human-relevant timeframe.

Parameters at Jettison

At the moment containment failure became inevitable, the Kugelblitz had been partially fed-down from its cruise mass in preparation for deceleration. Its terminal parameters at jettison were:

Parameter	Value	Notes
Terminal mass (M)	2.28×10^{5} kg	228 tonnes — partially depleted from cruise mass
Schwarzschild radius	$\sim 3.38 \times 10^{-22}$ m	Sub-nuclear — smaller than a proton by 6 orders of magnitude
Hawking temperature	5.38×10^{17} K	~34 billion times hotter than the sun's core
Hawking luminosity	6.85×10^{21} W	Power output at moment of jettison

Parameter	Value	Notes
Evaporation timescale	~1.0 seconds	Time from jettison to complete evaporation
Total burst energy (Mc^2)	2.05×10^{22} J	4.9 billion kilotons TNT equivalent

The Hawking Temperature Calculation

$T = \hbar c^3 / 8\pi GMk$

Where:

- $\hbar = 1.0546 \times 10^{-34}$ J·s (reduced Planck constant)
- $c = 2.998 \times 10^{8}$ m/s
- $G = 6.674 \times 10^{-11}$ m^3 kg^{-1} s^{-2}
- $M = 2.28 \times 10^{5}$ kg
- $k = 1.381 \times 10^{-23}$ J/K

Result: $T = 5.38 \times 10^{17}$ K

At this temperature the Kugelblitz was radiating across the full electromagnetic spectrum with peak emission well into the gamma-ray range. The containment fields were managing this radiation for thrust. When those fields failed — destabilised by Wei — 2.05×10^{22} joules of energy was released in approximately one second.

Part Two — The Ship

ARBOUR|05 Dimensions

Parameter	Value	Notes
Ship length	3,200 m	City-seed configuration — longer than any structure on Earth
Ship beam (width)	420 m	
End-on cross-section	~138,544 m^2	Circular profile — presented to burst by perpendicular jettison

Parameter	Value	Notes
Original mass	~4.5×10^8 kg	Fully laden with complement, colonisation equipment, and fuel. Read as dry/structural mass, not total launch mass — see Interstellar Navigation and Fuel Mathematics, Part Three, for the full reinterpretation and the much larger total launch mass figure (≈2.65×10^{10} kg), which implies once the full voyage's fuel consumption is accounted for.
Impact mass	~2.7×10^8 kg	~60% structural mass remaining post-cascade

Reactor Configuration

The five antimatter-catalysis fusion reactors were distributed along ARBOUR|05's longitudinal axis, with the drive section aft and the command and colonisation sections forward. This distribution determined which reactors survived.

Reactor	Location	Post-Jettison Status	Reason
R1	Forward — Frame 12	Fully functional	Shielded by ship mass from burst vector
R2	Forward — Frame 28	Fully functional	Shielded by ship mass from burst vector
R3	Mid — Frame 67	Partially functional	Partial shielding — took edge of EM surge
R4	Aft — Frame 112	Destroyed	Direct EM cascade exposure — containment failure
R5	Aft — Frame 134	Destroyed	Direct EM cascade exposure + residual antimatter detonation on impact

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Part Three — The Jettison Event

The Mission Specification Figure — 40.4 km

ARBOUR|05's mission specifications, Section 7.4.2 — Emergency Drive Jettison Protocols, defined the minimum safe separation distance for drive jettison as 40,400 metres (40.4 km).

This figure was calculated for a specific scenario: controlled, planned jettison of a fully evaporated drive assembly — a drive that had already been fed down to minimal mass and whose burst energy would therefore be orders of magnitude smaller than a live Kugelblitz.

It was not calculated for emergency jettison of a live Kugelblitz at terminal cruise mass, destabilised mid-voyage by sabotage no one had been able to name in time.

At 40.4 km, the energy received by the ship's hull from a 2.05×10^{22} J burst would have been:

$E_{received} = E_{total} \times A_{ship} / (4\pi r^2) = 2.05 \times 10^{22} \times 138{,}544 / (4\pi \times 40{,}400^2) = 1.38 \times 10^{17}$ J = 33,084 kilotons

The ship would not have survived. The 40.4 km figure was, in the context of what actually happened, meaningless.

Every engineer on ARBOUR|05 who understood the drive systems knew this.

What the Engineers Needed

To reduce hull impact to approximately 50 kilotons — severe damage, catastrophic to the aft section, but survivable for the forward hull — the required separation distance was:

$r = \sqrt{(E_{total} \times A_{ship} / (4\pi \times E_{target}))} = \sqrt{(2.05 \times 10^{22} \times 138{,}544 / (4\pi \times 2.09 \times 10^{14}))} = 1{,}039{,}220$ m ≈ 1,039 km

They needed 1,039 kilometres of separation. With the drive assembly fired on maximum thruster burn at approximately 50,000 m/s relative velocity, achieving 1,039 km of separation required:

$t = r / v = 1{,}039{,}000 / 50{,}000 = 20.8$ seconds

They had 21 seconds.

The Jettison Sequence

The drive assembly was fired perpendicular to ARBOUR|05's trajectory — maximising separation distance while minimising the end-on cross section presented to the burst. The perpendicular geometry meant the ship's circular end profile (138,544 m²) faced the burst rather than its broadside profile (~1,344,000 m²), reducing received energy by approximately 90%.

The engineering team held containment together for the full 21 seconds — fighting a destabilisation they did not yet understand the cause of. Then they fired the jettison bolts.

Jettison parameters achieved:

Parameter	Value
Separation at burst	1,039 km
Ship orientation	End-on to burst vector
Hull energy received	2.09×10^{14} J (50 kilotons)
Burst energy intercepted	0.000001% of total
Equivalent to	3.3 × Hiroshima

Part Four — The Electromagnetic Cascade

The burst reached ARBOUR|05's hull 3.47 milliseconds after jettison at the speed of light. What followed was a cascade measured in fractions of a second:

T + 0.000s — Burst EM wavefront reaches aft hull. ~50 kt energy absorbed by hull and aft structure. Aft section structural failure begins.

T + 0.003s — R4 magnetic containment bottle destabilised. Antimatter fuel begins uncontrolled interaction.

T + 0.007s — R5 magnetic containment bottle destabilised.

T + 0.012s — R4 and R5 initiate parasitic power drain from R1/R2/R3. Emergency protocol: attempt bottle restabilisation. Forward reactors begin power drain cascade.

T + ~0.05s — In the chaos of the failing containment and the realisation, only now fully grasped, of what Wei had done and was continuing to attempt, a group of crew members — accounts from survivors are inconsistent and no single name can be confirmed in the historical record — moved to stop him. Wei was killed in the confrontation. The destabilisation he had triggered could not be undone. By the time he was stopped, the cascade was already several steps beyond any single point of intervention.

T + 0.089s — Forward manoeuvring thrusters lose power. Unable to compensate — thrust below minimum for orbital maintenance.

T + 0.091s — Navigation control systems offline. SEED navigation partition loses power — data loss begins.

T + 0.340s — R4 containment collapses. Partial antimatter annihilation event. Structural deformation propagates forward.

T + 0.341s — Emergency power conduits severed by structural deformation. R1/R2/R3 now isolated — no longer draining, but no longer supplying aft.

T + 0.342s — R5 containment collapses. Partial antimatter annihilation event.

T + 4.200s — Engineering crew regains partial control of R1/R2 output. Available thrust: ~18% of nominal. Assessment: insufficient to prevent descent.

With Wei dead and no one else attempting to direct the ship's trajectory, ARBOUR|05's descent from this point was genuinely uncontrolled — not steered toward any target, deliberate or otherwise. What happened next was a function of physics, not intent.

Part Five — The Descent

Profile

Parameter	Value	Notes
Descent type	Uncontrolled ballistic re-entry	Navigation offline; no one alive attempting to direct trajectory
Available thrust	~18% nominal	R1/R2 only, partially drained
Ship mass at re-entry	~2.7×10^8 kg	60% structural mass
Approximate orbital velocity	7,902 m/s	Cordis-equivalent orbital speed
Estimated impact velocity	~3,161 m/s	Partial atmospheric braking
Kinetic energy at impact	~1.35×10^{15} J	~323 kilotons

The ship came down where the physics of an uncontrolled, partially-thrusted ballistic descent took it — not at a chosen or identified location. The site has no prior significance in any record, Penumbran or human. Arbour exists where it does because that is where the ship happened to stop, not because anyone, alive or dead, chose it.

Part Six — The Detonation and the Debris Field

R4 and R5 Residual Fuel

R4 and R5 had undergone partial annihilation events during the cascade at T+0.340s and T+0.342s. Their remaining antimatter fuel was partially contained within damaged magnetic bottles throughout the descent — unstable, degrading, but not fully annihilated.

Upon impact, the severing of the final emergency conduits caused simultaneous total containment collapse in both reactors. The remaining antimatter fuel annihilated completely.

Parameter	Value
Annihilation energy	1.80×10^{13} J
Kiloton equivalent	4.3 kilotons
Detonation type	Antimatter-matter annihilation
Location	Scattered impact zone — geologically unremarkable terrain, no prior name or significance

Reality Tear Interaction

The 4.3 kiloton annihilation detonation was not simply an explosion. It occurred within a region of the Penumbran Reach where reality tears — plural, scattered, none individually singular or pre-eminent — had been naturally present for millennia, the product of the Convergence's pressure against this reality's boundary in this part of the system.

The energy release interacted with the boundary conditions of the tears nearest the impact zone, permanently widening several of them. Aetheris intensity in the region increased by an estimated 340% in the immediate aftermath, based on data preserved in Wayfarer oral histories from the first four generations post-crash.

ARBOUR|05's wreckage became physically fused with the affected terrain at multiple points across the debris field — not embedded at one site but scattered and intertwined with the widened tears across the impact zone at a material level. There is no single location that can be called the crash site in any complete sense. There is only the debris field, and Arbour, built across and around it by people who did not fully understand what they were building on top of.

Part Seven — The 40.4 km Inscription

At some point between the jettison event and the impact — most likely in the chaos immediately following Wei's death, while the surviving crew were managing containment, the cascade, and what could still be salvaged of the ship's trajectory — someone went to the jettison control station and wrote on the bulkhead above it.

Three words and a number, in a hand that matched Chief Engineer [NAME — TBD through drafting]'s personnel file:

"*40.4. We knew. Sorry.*"

What "we knew" refers to is deliberately ambiguous and should remain so. It may mean the engineers knew the 40.4 km mission-spec figure was inadequate for a live Kugelblitz. It may mean the crew knew, before the destabilisation, that something was wrong with Wei, and did not act in time. Both readings should remain available to a reader — the inscription does not resolve which failure it is confessing to, and possibly the person who wrote it didn't fully separate the two in their own mind either.

The chief engineer died in the impact event. Their body was recovered in the first weeks post-crash and is recorded in the founding generation's mortality log.

The inscription was found by a maintenance crew in the second generation. It was reported to the proto-Council. The report was received, noted, and filed under reference AZ-1-0003-I in the earliest Tabularium records.

It does not appear in any index. It can only be found if you already know the reference number.

The reference number AZ-1-0003-I appears in one place: a footnote in a founding generation engineering report that was misfiled in the biological sciences archive rather than the technical archive, where it has remained for centuries, uncatalogued, in the wrong section, waiting.

Wren finds it on a Tuesday.

Part Eight — What Humanity Did to the Penumbran Reach

This is the conclusion that the mathematics leads to and that no one in Arbour knows.

The Penumbran Reach's reality tears were natural — the product of KOI-8565's binary stellar dynamics and the Convergence's pre-existing pressure against this reality in the system. They were stable over millennial timescales. Dangerous, yes. Worsening, yes. But slowly.

ARBOUR|05's arrival changed that.

The Kugelblitz burst — 2.05×10^{22} joules, released first at jettison and then again at the scattered impact site — interacted with the boundary conditions of the region's reality tears in the same way the impact-site detonation did, but at a cosmic scale for the jettison burst specifically. The jettison burst energy was orders of magnitude larger than the impact-site annihilation. Its effect on the Penumbran Reach's reality tears, system-wide, was proportionally larger.

Aetheris intensity in KOI-8565 did not merely increase after ARBOUR|05's arrival. It accelerated. The timeline that would have unfolded over further millennia was compressed into centuries.

Aetheris on Cordis is not simply a natural consequence of the Penumbran Reach's instability. It is a consequence of humanity's arrival. The engineers who jettisoned the Kugelblitz saved everyone aboard the ship. In doing so, they wounded the fabric of the system they had arrived in.

They did not know this. They could not have known this. They had 21 seconds, and a crisis they had not chosen, caused by a man none of them had been able to see was no longer entirely himself.

The Convergence does not hold this against humanity. The Convergence does not hold anything against anything — it is not capable of holding, in any sense that word means to a human. It is simply pressing where it always presses, completing a process that humanity accidentally accelerated by arriving at all.

This is the truth that sits beneath everything in Arbour. Not the Council's lie about the Blight. Not Wei's affliction. Not the founding deception.

Humanity came to KOI-8565 and made things worse. Not out of malice. Out of desperation and physics and 21 seconds that weren't quite enough, and a sickness in one good man that nobody recognised until it was already steering the ship.

Wren will find this too. Eventually.

Summary Table — Key Numbers

Parameter	Value	Significance

Kugelblitz terminal mass	2.28×10^5 kg	Determines all downstream calculations
Total burst energy	2.05×10^{22} J	4.9 billion kilotons
Hawking temperature	5.38×10^{17} K	~34B × solar core temperature
Evaporation timescale	~1.0 seconds	Burst duration
Mission spec safe distance	40.4 km	Irrelevant to actual event
Required safe distance	1,039 km	What they needed
Time available	21 seconds	What they had
Achieved separation	1,039 km	What they achieved
Hull energy received	50 kilotons	Cost of survival
EM cascade duration	0.342 seconds	R4/R5 destroyed; Wei killed within this window
Impact-site detonation	4.3 kilotons	Reality tears in the region permanently widened
Aetheris increase post-crash	~340%	Humanity's contribution
Survivors	~34% of complement	Because of 21 seconds

Open Questions for Drafting

- Open Questions for Drafting
  Cross-reference: the 323 kt impact figure (Part Five) and the 4.3 kt annihilation figure (Part Six) have since been used to calculate actual debris-field and Aetheris-hot-zone radii — see Arbour City Geography, "Scale, now locked with real figures." The two events produce two different scales (broad debris scatter vs. a much smaller, localised Aetheris-intense annihilation point); worth checking that document before assuming either figure alone describes "the debris field" as a whole.
- Chief Engineer's name and species — the inscription needs a face
- Full passenger/crew complement of ARBOUR|05
- Exact cruise mass of the Kugelblitz at departure from Earth
- Journey duration and relativistic time dilation figures (see: Interstellar Navigation appendix)
- Whether any record of the Kugelblitz burst's effect on the Penumbran Reach exists in Wayfarer oral history — and whether Sage Yahari knows what it means
- ~~"55 million times hotter than the sun's core" comparison~~ — **resolved.** This was a pure arithmetic error in the flavour text, unconnected to any other calculation in the document. The actual ratio between 5.38×10^{17} K and the Sun's core temperature (~1.57×10^7 K) is approximately 34 billion, not 55 million. Corrected in both the Parameters table and the Summary Table.

- **Wei's affliction concealment** — how did a man afflicted with Aetheris to a compromising, Stage Three/Four degree pass undetected aboard a ship presumably monitoring crew health closely? Was he hiding symptoms deliberately, in early stages unaware himself, or did something about command structure/trust mean nobody was positioned to flag it in time? Worth deciding, since it affects how sympathetic vs. culpable Wei reads in the historical record vs. however he's eventually depicted directly (flashback, found record, etc.)
- **Who killed Wei** — left deliberately unattributed in the historical record per the chaotic-response decision, but worth knowing privately (even if it never appears on the page) whether this was crew acting in coordinated self-defence, a single unrecorded act lost to the chaos, or something else
- **Does Wei know what's happening to him before the end** — a question with real weight for how tragic vs. how frightening this beat reads. Does he have any moment of horrified self-awareness, or is the affliction's takeover total by the time it matters?

Project Arbour Physics & Mechanics

1. Propulsion Systems Architecture

ARBOUR|05 relied on a tiered propulsion system to handle the distinct phases of interstellar colonisation.

Launch Phase: Metastable Metallic Hydrogen

Function: Escaping Earth's gravity well.

Mechanics: Utilized disposable, honeycomb-matrix launch cradles built from carbon-nanotube lattices. Metastable metallic hydrogen boasts a specific impulse roughly four times that of standard chemical rockets.

Lifespan: Entirely consumed or decoupled before the ark left the solar system. No relevance to Arbour's current infrastructure.

Primary Drive: The Kugelblitz

Function: Relativistic interstellar transit.

Mechanics: An artificial black hole (Schwarzschild metric, uncharged) suspended in a macro-Penning trap via superconducting electromagnets.

Lifespan/Mass: To provide continuous, petawatt-level thrust for decades, it began with a mass of roughly 2×10^9 kg. It was actively "fed" matter/lasers during transit to prevent exponential Hawking evaporation.

Evaporation Equation: $t = 5120\pi G^2 M^3 / \hbar c^4$

Secondary Drive: Antimatter-Catalysed Fusion

Function: In-system manoeuvring, deceleration, orbital insertion, and internal life support (Reactors R1 through R5).

Mechanics: Uses microscopic amounts of antiprotons to induce fusion in standard isotopes (deuterium-tritium).

Consumption: A 1-Gigawatt output reactor consumes roughly 0.45 milligrams of antiproton catalyst per year.

Catalytic Function vs. Containment Failure: Under normal operation, antiprotons are not themselves the fuel — they catalyse fusion in deuterium-tritium isotopes, triggering far more energy release than the antiprotons' own rest mass would account for, while the antiprotons themselves are largely recycled through the reaction rather than consumed by annihilation. This is why the per-gigawatt-year consumption figure above is so small: catalysis, not destruction. A magnetic containment failure is a different physical event entirely — antiprotons released from confinement encounter normal matter directly and annihilate completely, converting their full rest mass to energy via $E = mc^2$. This is the failure mode that occurred in R4 and R5; it is not simply "more of the same reaction running out of control," but a different process altogether, which is why a relatively small residual quantity of catalyst was capable of the yield recorded below.

The Vault: The suppressed secondary power plant in Arbour contains an untouched reserve of this antiproton catalyst, making it a literal ticking countdown to city-wide power failure if not retrieved.

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2. Earth Launch Logistics

Constructing continental-scale megastructures on a terrestrial surface required overcoming immense hydrostatic, aerodynamic, and acoustic challenges.

Deep-Water Trench Assembly

The ships were constructed in semi-submerged oceanic drydocks. The water provided uniform hydrostatic pressure, acting as a massive cradle that prevented the kilometre-scale frames from buckling under Earth's gravity (1G) during the decades of assembly.

Acoustic & Aerodynamic Suppression

Launching a ship of this volume using metallic hydrogen would displace millions of tons of air and generate decibel levels capable of liquefying tissue and shattering rock.

- **Acoustic Damping:** Launching directly out of the deep ocean utilized millions of tons of water as a mandatory sound-suppression chamber.
- **Temporal Spacing:** Launches were staggered by months or years to allow the global atmosphere to recover from the hyper-sonic pressure waves.
- **Cleanup:** Launch cradles largely incinerated in the upper atmosphere. Construction drydocks were scuttled into the abyssal plain, using tectonic subduction and immense pressure to "recycle" the hazardous materials.

The Five Arks — Oceanic Build Locations

Ark	Trench Basin Location	Strategic Engineering Rationale
ARBOUR|01	Mariana Trench	Deepest site; optimized for extreme hydrostatic pressure hull integrity testing.
ARBOUR|02	Java Trench	Equatorial position; optimized for fuel-efficient orbital insertion.
ARBOUR|03	Puerto Rico Trench	Atlantic isolation; ensures industrial security during construction.
ARBOUR|04	Peru-Chile Trench	Southern polar trajectory; isolates atmospheric shockwaves from the Northern Hemisphere.
ARBOUR|05	Point Nemo Basin	The "Pole of Inaccessibility." Maximum geographical isolation. Utilized Earth's existing "spacecraft graveyard" to hide the massive construction footprint and debris.

Cross-reference: this is the first appearance of build locations for ARBOUR|01 through |04. The fate of these four ships remains series territory per the handoff summary and is not addressed here.

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3. ARBOUR|05 Pre-Crash Configuration

Mass distribution was critical. To survive relativistic speeds, the massive liquid coolant reserves and secondary reactors (R1, R2, R3) were placed at the forward section to act as kinetic and radiation shielding, while the highly volatile Kugelblitz and remaining reactors (R4, R5) were at the

aft.

4. The Catastrophe at KOI-8565 (Cordis)

The crash of ARBOUR|05 was not random; it was the result of a precise, calculable sequence of physical failures — triggered not by an external anomaly, but by a man.

Sequence of Events

The Trigger: As the ark approached Cordis, engineers had intentionally "starved" the Kugelblitz so it would evaporate upon arrival, providing a final braking manoeuvre. Dr. Jian Wei — whose concealed Aetheris affliction had, by this point in the voyage, begun compromising his judgment and autonomy without anyone around him recognising it for what it was — destabilised the Schwarzschild magnetic containment field exactly as the singularity reached its exponential terminal heat phase. Whether this was a deliberate act, a compelled one, or something Wei himself could no longer have drawn a clear line between, is not established in the record and is unlikely ever to be.

The Jettison: Facing imminent vaporisation, the engineers manually ejected the primary drive assembly out the aft hatch. (Full mathematics of the jettison sequence, the 21-second window, and the achieved separation distance: see *Kugelblitz Jettison Mathematics*.)

The Pulse: At precisely 40.4 kilometres away from the aft shielding, the Kugelblitz reached a mass of 2.28×10^5 kg. One second later, it evaporated completely, converting to energy ($E = mc^2$). It released a Hawking radiation burst of 2.05×10^{22} Joules.

The Parasitic Drain: The electromagnetic pulse struck the aft shields. The surge destabilized the magnetic bottles holding the antiproton reserves in reactors R4 and R5. To prevent immediate internal annihilation, R4 and R5 failsafes activated, parasitically draining gigawatts of power from the forward grid (R1, R2, R3) to hold their fields.

Wei Stopped: In the chaos of the failing containment, a group of crew members — accounts are inconsistent and no single name can be confirmed in the historical record — moved to stop Wei. He was killed in the confrontation, within the same narrow window as the early cascade. By then, the destabilisation he had triggered could not be undone; the cascade was already several steps beyond any single point of intervention. (See *Kugelblitz Jettison Mathematics*, Part Four, for the precise timestamp within the EM cascade.)

Decelerator Failure: Starved of power by the aft drain, the forward in-system manoeuvring thrusters shut down. ARBOUR|05 lost its sub-relativistic braking capacity and was pulled into Cordis's gravity well. With Wei dead and no one else attempting to direct the ship's trajectory, what followed was genuinely uncontrolled — not steered toward any target, deliberate or otherwise.

Impact and Annihilation: The ark impacted Cordis at an unremarkable, unchosen location. The kinetic shockwave severed the emergency power conduits, cutting off the parasitic drain. The magnetic containment in R4 and R5 collapsed instantly.

The 4.3-Kiloton Blast: The remaining 200 milligrams of antiproton catalyst, no longer confined, annihilated directly with normal matter — full rest-mass conversion, not catalysed fusion (see Section 1). 200 mg of mass converted via $E = mc^2$ yields:

$E = mc^2 = 0.0002\ \text{kg} \times (2.998 \times 10^8\ \text{m/s})^2 \approx 1.80 \times 10^{13}\ \text{J}$

Equivalent to 4.3 kilotons of TNT — consistent with the figure locked in *Kugelblitz Jettison Mathematics*, Part Six.

The Result: The explosion scattered wreckage and reactor housing across the impact zone — not a single dramatic crater, but a diffuse, geologically unremarkable debris field. There is no "Heart." Arbour was built where the ship happened to come down, not the reverse. (See *Kugelblitz Jettison Mathematics*, Part Six, and the glossary's *Debris Field* entry.)

The immense physical distance and the structural mass of the Habitation Cylinder insulated the forward reactors (R1, R2, R3). They survived to power the city of Arbour, forever scarred by the failures of their arrival — and by the man whose unrecognised affliction caused them.

Open Questions for Drafting

- ~~Internal consistency check on blast-yield figures~~ — **resolved.** The original 100 mg antiproton-catalyst figure didn't reconcile with the stated 0.2 g mass-equivalent conversion (100 mg fully converted yields only ~2.1 kt, half the stated 4.3 kt). Corrected to 200 mg, which produces a clean, internally consistent chain: 200 mg → 0.2 g rest-mass equivalent → 1.80×10^{13} J → 4.3 kt, matching *Kugelblitz Jettison Mathematics* exactly. Also added an explicit note (Section 1) distinguishing the antiproton catalyst's normal catalytic role from its direct annihilation behaviour during a containment failure, since these are physically distinct processes and the document previously left that distinction implicit.
- ~~Reissner-Nordström vs. Schwarzschild labelling~~ — **resolved.** The Kugelblitz was described as a Reissner-Nordström (charged) black hole, but every actual calculation in *Kugelblitz Jettison Mathematics* uses the standard Schwarzschild (uncharged) formulas. The numbers were never wrong — only the label didn't match the math being used. Corrected both occurrences in this document to "Schwarzschild."

- The fate of ARBOUR|01 through |04, now that their Earth build locations exist — still series territory, not Book One.
- Whether Wei's affliction was deliberate concealment, early-stage unawareness, or something in between remains undetermined per the existing Kugelblitz Jettison Mathematics open questions — this document inherits that same ambiguity rather than resolving it independently.

Interstellar Navigation and Fuel Mathematics

Lives in: Technical Appendices. Companion to Kugelblitz Jettison Mathematics and Propulsion & Launch Logistics, which this document precedes chronologically (the journey, before the jettison that ends it). This is the foundation for any future map, route diagram, or stellar-neighbourhood document — distance, direction, and journey duration are locked here first, so every visual built afterward is consistent with the same numbers.

Overview

ARBOUR|05 did not travel far in galactic terms, and it did not travel for long in the terms that mattered to the people aboard it. It travelled exactly as far as the Kugelblitz could carry a ship of its mass within a single working lifetime, to the nearest system that offered any real chance of survival. Nothing about the destination was chosen for what it was. Everything about it was chosen for where it happened to be.

Part One — Distance and Direction

The Figure

Distance: 40.0 light years.

This is deliberately a clean, central figure within the band of distances a 1g-constant-acceleration Kugelblitz voyage can cover inside a single crewed working lifetime (see Part Two). It is not the closest star to Earth, and not a remote, multi-generational reach — it is the closest *viable* system within the ship's real range, which is the entire point: Project Arbour was not choosing a destination. It was finding the nearest place the math said the ship could actually reach with people still alive and capable of running it at the other end.

Direction — Cygnus

KOI-8565 sits in the direction of the constellation **Cygnus**, consistent with the existing KOI (Kepler Object of Interest) naming convention already locked into this setting's terminology. This is not incidental — it is the *origin* of the naming convention, not just flavour layered on top of it. The real Kepler space telescope's entire primary mission stared continuously at one fixed patch of sky overlapping Cygnus and Lyra, because that field offered the deepest, most star-rich view available without the Sun ever crossing into frame. Every real KOI designation comes from a star inside that one patch. A fictional KOI-8565 sitting in the same direction is not a coincidence layered in after the fact — it is simply what the name has always implied, made explicit.

This gives Cygnus a quiet, load-bearing role across the whole setting: it is the direction Project Arbour looked when looking for somewhere to go, the direction the five arks were launched toward (at least ARBOUR|05 — see Part Four on the others), and, by extension, the direction in Cordis's sky that points back toward a home nobody aboard will ever see again. Worth keeping in mind for any future scene that puts a character under open sky and gives them a reason to look up.

Real star systems in this general distance band and direction exist (e.g. Gliese 806, ~40 light years, Cygnus) — KOI-8565 is fictional and does not correspond to any specific real catalogued object. The placement is directionally and distance-accurate to this setting's needs without claiming any real star as its basis.

Part Two — The Voyage

Propulsion Profile

The Kugelblitz provided constant, controlled thrust for a standard relativistic **brachistochrone profile**: continuous acceleration at **1g** (9.81 m/s², ordinary felt gravity) for the first half of the journey, followed by continuous deceleration at the same rate for the second half — accelerating away from Earth, decelerating into KOI-8565. This is consistent with existing canon's description of the drive providing "controlled Hawking radiation thrust" throughout the voyage, with a final, deliberate run-down of the black hole's mass "in preparation for deceleration" as the ship approached Cordis (see *Kugelblitz Jettison Mathematics*).

A constant 1g profile is also the most survivable and humane option available for a crewed, conscious, working voyage — the people aboard experienced ordinary gravity for the entire trip, not crushing acceleration or prolonged weightlessness. This matters for a crew that needed to remain capable of research, maintenance, and (per existing canon) the kind of close working relationships and reputational dynamics already established for the founding generation.

Locked Figures

Parameter	Value
Distance	40.0 light years
Acceleration profile	Constant 1g, symmetric accelerate/decelerate (brachistochrone)
Experienced (proper) time aboard ship	**7.30 years** (≈ 2,665 days)
Earth-frame (coordinate) elapsed time	41.89 years
Peak velocity (at trip midpoint)	96.65% of c
Peak Lorentz factor (γ)	3.90
Turnaround point	3.65 years experienced / 20 light years travelled

What This Means

Aboard the ship, the voyage took a little over seven years — long enough to be a real, defining chapter of an adult crew member's working life, short enough that the people who left Earth and the people who arrived at Cordis were unambiguously the same individuals, not descendants of the original crew. This is consistent with everything already established about the founding generation: Wei conducted "final experiments... during the voyage" and "acquired" his Aetheris affliction during it, meaning he was awake, working, and himself for most of the trip before it caught up with him near the very end. A 7.3-year voyage supports this directly — long enough for an affliction to develop gradually and be missed, short enough that there was only ever one crew, never a second generation born and raised in transit.

On Earth, nearly 42 years passed during the same voyage. This is the genuine cost of relativistic travel that the crew would have understood intellectually before departure and felt as a real, permanent loss only once underway: whoever and whatever they left behind aged, changed, and in many cases died during a voyage that, from the crew's own perspective, took a fraction of that time. Project Arbour's five arks left a dying Earth behind; for ARBOUR|05's crew specifically, they left it roughly six times faster than they themselves aged away from it. By the time of jettison and crash, anyone still alive on Earth — if Earth's own crisis allowed anyone to still be alive — was living in a year the crew would have to do real arithmetic to even name.

This is also worth holding next to The Great Stripping. The Magnetosphere Collapse was already, per that document, a fast-moving, terminal crisis on a timescale of months and years at launch. Layered against a 42-year Earth-frame gap during ARBOUR|05's voyage alone, the Earth the crew left and the Earth that existed by the time they reached Cordis are almost certainly not the same Earth in any meaningful sense — whatever final state the Great Stripping reached, the crew's own information about it was already decades stale before the ship was even halfway there.

Part Three — Fuel and Propulsion

Why a Kugelblitz, Specifically

A near-future humanity capable of building five ark-scale ships and launching them within a compressed, crisis-driven timeline (per *The Great Stripping*'s 6-month launch cadence) would not have had access to genuinely exotic, unproven propulsion at full engineering maturity. A Kugelblitz — a microscopic, artificially sustained black hole used as a controlled Hawking-radiation thrust source — sits at the edge of plausible near-future engineering: it requires no fuel in the conventional combustion sense, generates thrust directly from spacetime physics rather than reaction mass, and (critically, for a 40-light-year 1g voyage) does not require carrying anywhere near the propellant mass a conventional reaction drive would need to sustain relativistic acceleration for years on end.

This is consistent with existing canon's framing: "the only propulsion system capable of accelerating a vessel of ARBOUR|05's mass to the relativistic speeds required... within a human-relevant timeframe." The Kugelblitz is not exotic dressing. It is the one piece of physics that makes the entire premise — a single-generation, conscious, crewed interstellar voyage — function at all.

Fuel Budget — Complete

Mechanism: pure photon rocket. The Kugelblitz's Hawking radiation provides thrust directly via radiation pressure — 100% of consumed reaction mass converts to thrust-generating radiation, with no separate propellant heated and exhausted at sub-light speed. This is the simplest mechanism consistent with existing canon's "controlled Hawking radiation thrust" framing, and — while it demands the largest possible fuel mass of any thrust mechanism for a given velocity change — it is also the most fuel-*efficient* per unit of thrust achievable by any rocket, since photon exhaust velocity (c) is the theoretical maximum. Any slower-exhaust alternative would have required *more* total fuel mass for the same trip, not less.

A necessary reinterpretation of the existing mass figure. *Kugelblitz Jettison Mathematics* lists ARBOUR|05's "original mass" as ~4.5×10^8 kg, noted as "fully laden with complement, colonisation equipment, fuel." For the mass-ratio mathematics below to work at all, this figure is best read as the ship's **dry/structural mass** — hull, complement, colonisation equipment, and whatever fuel happened to be aboard at any given snapshot — rather than the *total* fuel ever consumed across the full voyage. This is a reasonable, non-contradictory reading: no real vessel's "fully laden" mass figure typically accounts for the entire fuel supply burned over a multi-year journey as a separate, additional figure. The total fuel consumed across the voyage, calculated below, is a much larger number than the ship's loaded operating mass at any one moment — consistent with how relativistic photon-rocket fuel economics actually work.

The relativistic rocket equation. For a photon rocket completing a symmetric brachistochrone (accelerate to peak velocity, then decelerate by the same amount), the required mass ratio is set by the rapidity (not velocity) achieved at turnaround. At the locked peak velocity of 96.65% c (Lorentz factor γ ≈ 3.90), the rapidity at turnaround is φ ≈ 2.037, giving a mass ratio of e^φ ≈ 7.67 per leg, or **≈58.8 for the full round-trip-equivalent burn** (accelerate, then reverse and decelerate).

Parameter	Value
Dry mass (structure, complement, colonisation equipment)	4.5×10^8 kg
Total mass ratio (full symmetric 1g brachistochrone, photon rocket)	≈58.8
Total launch mass (dry + fuel, departing Earth)	**$\approx 2.65 \times 10^{10}$ kg**
Total fuel mass consumed across the full voyage	**$\approx 2.60 \times 10^{10}$ kg**
Fuel as fraction of total launch mass	98.3%
Fuel consumed during the acceleration leg (Earth → turnaround)	$\approx 2.30 \times 10^{10}$ kg
Fuel consumed during the deceleration leg (turnaround → Cordis)	$\approx 3.00 \times 10^9$ kg

What the fuel actually was. The bulk reaction mass feeding the Kugelblitz across the voyage is almost certainly ordinary matter — water or hydrogen ice — not the precious, small-quantity antiproton catalyst already established as fueling R1 through R5 (per *Propulsion & Launch Logistics* , reactor fuel consumption runs at fractions of a milligram of antiproton catalyst per gigawatt-year; that fuel category is structurally incapable of supplying a 26-billion-kilogram reaction mass budget, nor was it ever meant to). This dovetails directly with existing canon's own description of "massive liquid coolant reserves" placed at the forward section specifically to shield R1, R2, and R3: the most economical design is one where the same mass serves double duty — kinetic and radiation shielding during cruise, progressively consumed as Kugelblitz reaction mass across the voyage.

This produces a genuinely useful, dramatic consequence. Because fuel consumption is sharply asymmetric — roughly 23 billion kg burned during acceleration against only 3 billion kg during deceleration — the ship's forward shielding mass was thickest at departure from Earth and thinnest by the time it actually reached Cordis. The cascade that destroyed R4 and R5 therefore struck the ship at its most fuel-depleted, most structurally vulnerable point of the *entire* voyage — not an arbitrary moment of bad luck, but the single worst possible time, mass-budget-wise, for anything to go wrong. This sharpens, rather than contradicts, *Kugelblitz Jettison Mathematics*' own framing that "the ship would not have survived" the originally-calculated 40.4 km safe-separation distance: by the time of the actual emergency jettison, ARBOUR|05 was carrying a small fraction of the shielding mass it had departed Earth with.

Part Four — Why the Penumbran Reach, Specifically

KOI-8565 was not chosen. It was the closest system within ARBOUR|05's real fuel and structural range that offered any plausible chance of a survivable arrival — a planet, or near-planet conditions, reachable within the distance a Kugelblitz-class drive could cover before the ship's resources, and the crew's working lifetimes, ran out. This is consistent with the entire emotional register already established for this setting: nothing about Project Arbour's founding moment was generous or considered. It was triage, exactly as the Committee's "no-choice gambit" and the six-month launch cadence already establish for the decision to leave at all. The choice of where to go was the same kind of decision, made under the same kind of pressure, by people who did not have the luxury of choosing somewhere good — only somewhere reachable.

This means the Penumbrans' presence in this system was never anticipated, never a factor in the original targeting, and never something Project Arbour's planners on Earth had any reason to suspect. Whatever ARBOUR|05's crew found when they arrived — the binary stellar dynamics, the ancient reality tears, the dead native civilisation and its installations — was discovered, not sought. The system was significant only after arrival, never before it.

Whether this distinguishes ARBOUR|05 from the other four arks is deliberately left open. Per *The Five Arks*, each ark was launched toward "a different direction of known space," and per that document's own design principles, no thread should imply the other arks share ARBOUR|05's specific situation. It is entirely possible — and left undecided on purpose — that the other four arks found genuinely empty systems, genuinely hospitable ones, or their own version of an ancient and inhabited Reach. This document does not resolve that. It only confirms that ARBOUR|05's own situation was accidental, not engineered, and not predictive of what the series may eventually reveal about the others.

Part Five — The Outer-System Stop

A Margin Worth Explaining

The fuel budget locked in Part Three accounts for a complete, planned voyage — but it leaves essentially no margin for anything unplanned. By the time ARBOUR|05 began final approach to Cordis, the ship was already carrying close to its minimum viable mass; any meaningful deviation from the planned brachistochrone (a course correction, a delay, an unplanned manoeuvre) would have eaten into a reserve that the numbers above show barely existed. This document does not require an additional fuel source to make the locked voyage mathematics work — but it leaves

room for one, and there's a strong, story-useful reason to use it.

What Happened

Before committing to the final approach toward Cordis specifically, ARBOUR|05 made a brief survey stop in KOI-8565's outer system — consistent with ordinary, cautious voyage procedure: confirming the target system's actual conditions before committing the ship's remaining fuel margin to a specific final destination, rather than assuming Cordis was survivable on faith. During this stop, long-range scanning detected an anomalous structure consistent with what would later be classified, after the fact and after the Penumbrans were understood to have existed at all, as a wellspring-type Installation — a structure built to generate, store, or channel energy connected to Aetheris/the Hum, the Penumbrans' closest equivalent to a power plant. At the time, it registered as simply an artificial structure radiating detectable energy in a system that should have contained nothing artificial at all.

A scope note, worth being precise about: this establishes only that the Penumbrans were capable of reaching and building in their *own* system's outer reaches — a moon, a distant rocky body, or a stable orbital structure, built and reached the ordinary way any species with tens of thousands of years of continuous civilisation in one system would eventually manage. It does not establish, imply, or require interstellar travel of any kind. The Penumbrans never needed to leave KOI-8565 to build something out past Cordis's own orbit; their reach was wide within their own system, not beyond it. This is fully consistent with existing canon's framing of them as a civilisation defined by staying — "to them, the Reach was not a dangerous frontier — it was simply home" — rather than one defined by going anywhere else.

The crew did not investigate it for what it was. They had no framework yet for "an ancient civilisation's installation" — there was no Penumbran/First-Walked concept yet for anyone aboard to reach for. What they investigated was a structure radiating detectable, anomalous energy in a system otherwise unremarkable, and what they took from it was not understanding but **raw material and residual energy** — crudely extracted, harvested rather than operated, in the same spirit as scavenging usable parts from wreckage rather than reverse-engineering a working machine. Nothing about the Installation was activated, operated, or comprehended. Something was simply taken from it, the way a desperate crew with a thin fuel margin takes whatever usable mass and energy presents itself.

Dr. Jian Wei led this integration. As the crew member with the deepest working knowledge of the Kugelblitz's own feed systems, he was the natural choice to assess whether the harvested material and energy could be safely fed into the drive at all — and he was, by extension, the person who spent the most sustained time in direct proximity to the Installation and what was taken from it. This does not require Wei to have understood anything about what he was working with. It only requires that he was closer to it, for longer, than anyone else aboard.

Why This Matters

It is the missing origin point for Wei's affliction. Existing canon already states his Aetheris affliction was "acquired during the voyage" and had, "by this point in the voyage" — final approach — "begun compromising his judgment and autonomy." Until now, nothing in any document specified *where* aboard a multi-year voyage through otherwise unremarkable space that exposure could plausibly have come from. The outer-system stop answers this directly: Wei's affliction began at the Installation, seeded by sustained proximity to harvested Penumbran material during integration, and worsened gradually across the remaining transit time to Cordis — consistent with the existing, locked framing that nobody recognised what was happening until it was already happening.

It does not compromise the Penumbrans' unknowability. Nothing here decodes their writing, operates their technology, or resolves the ascension-versus-erasure ambiguity. The crew scavenged the way a person might strip copper wire from a ruin without reading a word of what's carved into its walls. What they took, they took blind — which is, if anything, consistent with how little anyone in this setting ever truly understands about what they're handling where Aetheris is concerned.

It adds a small, genuine margin to the fuel budget without requiring Part Three's locked figures to change. The harvested mass and energy are best understood as exactly enough to cover the unplanned cost of the survey stop itself and provide a thin safety margin into final approach — not a windfall, not enough to meaningfully alter the voyage's overall numbers, consistent with the "just enough to reach a habitable planet" scale this was always meant to be.

Part Six — Does the Math Actually Support a Ship This Size?

A direct answer, worth stating plainly rather than leaving implicit: **yes, internally — and the scale it confirms is enormous, deliberately so.**

The full locked figures: 4.5×10^{8} kg dry/structural mass, 2.60×10^{10} kg of fuel consumed across the voyage, **2.65×10^{10} kg total launch mass.** Every figure across both documents is internally consistent — dry mass plus fuel mass equals total launch mass, the mass ratio matches the locked velocity profile, nothing contradicts anything else already established.

What that total launch mass actually represents, in real terms, is worth sitting with rather than glossing past: roughly four to five Great Pyramids of Giza, around fifty times the largest supertanker ever built, with the fuel alone running to a noticeable fraction of a full year of all the steel humanity currently produces — for **one ship**, of **five** launched within a compressed, crisis-driven timeline (see *The Great Stripping*'s six-month launch cadence).

This is not a strain on the setting's plausibility. It is the setting's plausibility, made concrete. Every piece of existing canon around Project Arbour's founding already describes a species spending everything it has, with no reserve and no second attempt possible: the Committee's "no-choice gambit," a launch cadence dictated by a closing atmospheric window rather than readiness, five ships built in five separate deep-ocean drydocks simultaneously because there was no time to build them in sequence. A ship that costs several Pyramids' worth of mass to launch is not an inconsistency to explain away. It is the precise, load-bearing reason Project Arbour could only ever happen once, could only ever launch five ships, and could never have sent help, supplies, or a second wave after them. The math doesn't just support a ship this size — it explains why there was only ever going to be five of them, and why nothing came after.

Open Follow-Ups

- [x] **Scope guard: the outer-system Installation does NOT establish Penumbran interstellar travel.** Flagged explicitly because the discovery could easily be misread that way. It establishes only in-system reach (their own star's outer bodies), fully consistent with their existing "civilisation defined by staying" framing. If interstellar Penumbran travel is ever deliberately wanted in a later book, that would need to be a separate, conscious decision — not an accidental inheritance from this document.
- [x] What kind of Installation this was, specifically. ✓ Resolved — wellspring-type, a new fourth Installation subtype (energy generation/storage, distinct from reliquary, observatory, and habitation site) added to the framework specifically to explain this discovery. See World Systems → The Penumbrans, Section 3, for the full entry. This is also now the established in-world explanation for why the structure registered as "radiating detectable, anomalous energy" and had anything extractable for the crew to crudely harvest.
- [ ] **Whether this Installation is ever revisited, found, or referenced again** — by Wren, by Wayfarer tradition, or in a later book. Currently a self-contained origin point for Wei's affliction; could be left that way, or seeded forward.
- [ ] **The "private continuity note" question** — per the Generation Two suppression figure and Wei-affliction open items already tracked elsewhere, this is exactly the kind of detail that should be privately consistent (does anyone in the founding generation's surviving records describe the outer-system stop honestly, or was it folded into the same silence as everything else What ARBOUR|05 Knew already covers?) even if it never appears on the page directly.
- [x] **Full fuel/feed-rate mathematics for sustained Kugelblitz cruise mass** — RESOLVED. Pure photon rocket mechanism locked; total fuel mass (~2.60×10^{10} kg, ~98.3% of total launch mass) and the asymmetric accel/decel consumption split calculated. See Part Three.
- [x] Reconciling the "4.5×10^{8} kg original mass" reinterpretation with Kugelblitz Jettison Mathematics' own table. ✓ Resolved. A clarifying note now sits directly in that document's dimensions table, pointing to the dry-mass reinterpretation.

- [ ] **Precise galactic coordinates / a specific fictional position within the Cygnus direction** — this document locks distance (40 ly) and general direction (Cygnus) but does not place KOI-8565 at specific right ascension/declination coordinates. Worth doing if a detailed star-system or stellar-neighbourhood map is built.
- [ ] **Whether any reserve Kugelblitz fuel/feed-matter survived the crash and plays any role in Arbour's current power or propulsion infrastructure** — flagged as an open question by the original To-Do scoping for this document. Given the fuel budget above, very little reaction mass would plausibly have remained unconsumed by arrival (the ship was near its post-deceleration dry mass by the time of the crash) — worth deciding deliberately rather than assuming a reserve exists.
- [ ] **The other four arks' directions and distances** — deliberately out of scope per *The Five Arks*' own design principles (series territory, not Book One). This document's numbers should not be used to infer anything about them.
- [ ] **A dedicated stellar-neighbourhood / KOI-8565 system map**, and **a full Cordis planetary map**, and **a route-from-Earth diagram** are now unblocked by this document's locked figures — see companion diagrams.