

PROPOSAL REQUEST FOR GATE A FUNDING

PROBE, 0.20c

Lunar Starshot

A staged programme to send gram-scale StarChip probes from the far side of the Moon to Proxima Centauri.

0.20c

CRUISE SPEED

3.56 g

PROBE MASS

269 GW

LASER BEAM

10,000

PROBES

~Year 45

FIRST DATA

CONCEPT VISUALISATION

INDEPENDENT PROPOSAL BY GUY. NOT AFFILIATED WITH, ENDORSED BY, OR
A RESTART OF BREAKTHROUGH STARSHOT.
LUNAR TEXTURE: NASA'S SCIENTIFIC VISUALIZATION STUDIO.

Contents

01	The first attempt	3
	Where Breakthrough Starshot stopped, and how this differs	
02	Executive summary	4
	The ask: Gate A, about \$160 million, two years	
03	Why now	5
	What changed, and what it does not prove	
04	The mission at a glance	6
	One probe, launch to first data	
05	The spacecraft	7
	Sail, tendons, StarChip and dust pod	
06	Riding the beam	8
	Tilt, drift, Doppler sweep and flutter	
07	The lunar departure point	9
	Array, industry and power	
08	The campaign	10
	100 cohorts of 100 probes	
09	Cost and uncertainty	11
	Where the money goes, and the range	
10	The first questions	12
	Laser band, sail structure and heat	
11	The staged programme	13
	Four gates, each able to stop the work	
12	Risks and open questions	14
13	Relationship to Breakthrough Starshot	15
	Independence, differences and governance	
14	References and sources	16
A	Appendix: reference data	17

About this paper

This is a proposal from GUY (Guy Gendell), contact@lunarstarshot.com. Its mission numbers come from the Lunar Starshot design study, Baseline Z (Revision BA), and its staged budgets from the study's development roadmap. Figures are rounded, and we write "about".

The study has not been independently reproduced. Every figure is a model output until a gate measures it.

Labels used

CONCEPT

Illustration. Not to scale and not a design drawing.

NOT COSTED

Part of the proposal that the reference cost does not include.

STUDY VALUE

Output of the design model, not a measurement.

Money

US dollars on the study's cost basis. No inflation, discounting or financing convention has been fixed yet.

Independence

GUY is independent. This proposal is not endorsed by Breakthrough Initiatives and is not a restart of Breakthrough Starshot. Starship is our planning choice for heavy lunar cargo, not a finding of the study. No SpaceX partnership or contracted delivery is implied.

This edition

Revision BA, October 2026: ytterbium lasers near 1 μm , a broadband sail grating and a smaller 2.8 m sail reach 0.20c, with no margin left in the laser band, at about \$574 billion (P10–P90 \$323–1,171 billion). A thulium design (0.12c, about \$502 billion) is the fallback.

Where the first attempt stopped

Breakthrough Starshot put laser-driven interstellar flight on the research agenda in 2016, with about \$100 million of research funding and a public list of 29 engineering challenges. As press coverage summarised it, the goal was to send gram-scale probes at about a fifth of the speed of light and reach the Alpha Centauri system within roughly 20 years. In September 2025 Scientific American reported that the effort was on indefinite hold, without a formal closing announcement [1].

We rely on that public report and do not claim to know why the programme paused. This proposal is independent: it is not endorsed by Breakthrough Initiatives and does not restart or continue Breakthrough Starshot. What follows sets out the hard problems that were openly acknowledged, from public sources, and how this design study answers each one.

The study behind this paper replaced each ideal assumption with physics. The result keeps Starshot's core idea and changes almost everything about how it is carried out.

THE PROBLEMS THAT WERE STILL OPEN

Keeping a sail on the beam

A flat, nanometre-thin film pushed by an intense beam tends to slide off it, tip over or ripple itself apart. Staying centred and stable was an open research question, not a solved one.

Surviving the light

Even a tiny absorption in a film that thin, under a beam that bright, turns into heat the film cannot shed. How hot the real material runs was never measured.

Firing through the sky

A kilometre-scale laser array on the ground must push its beam through air that blurs, bends and absorbs it, and hold a pointing steadiness far beyond anything built.

Dust at a fifth of light speed

At 0.2c a grain of interstellar dust hits like a bullet. Protecting a gram of electronics for the whole cruise was unsolved.

A research budget, not a built path

The programme was \$100 million of study. There was no staged plan that turned measurements into a decision to build, or stopped early if they failed.

WHAT THIS DESIGN CHANGES

The laser moves to the far side of the Moon

No atmosphere to blur or absorb the beam, no weather, and sunlight most of the time on the polar ridges. The kilometre-scale mirrors and structure are made on the Moon from regolith rather than launched. Earth never rises over the far side, which is also a useful safety limit.

The sail is stiffened, not a loose film

It is a curved silicon-carbide ring-grating dome with a 15 nm back face on a 6 cm fibre-truss core, held by a tendon net and spun during the burn. Flown in a hollow beam shaped in amplitude and phase, and wavelength-swept to track the Doppler shift, it **shows no flutter in the models**, linear and nonlinear. It has not been built or tested, and the flutter check has three stated limits.

The light is near 1 μm , not 2 μm

At the shorter wavelength the sail heats about three times less and the grating concentrates the field about three times less, so hot silicon carbide no longer runs away. A 1,300 K material ceiling sets the limit instead, with margin to spare in the models.

The money is gated

Four gates, each able to stop the work. The first ask is about \$160 million for two years of laboratory measurements. About 98% of the spend is committed only after a separate build decision, and only if the measurements pass.

Three things are still unproven: the laser band has zero margin at 0.20c, the sail's hot absorptance has never been measured, and the self-pointing dust shield has not been validated. Gate A measures all three first, cheaply, and the build goes ahead only if they pass. A side-by-side comparison with Starshot as publicly described is in section 13.

Measure first. Build only if the measurements pass.

GUY proposes a laser-sail mission to Proxima Centauri, launched from the far side of the Moon. We ask for about \$160 million over two years to fund Gate A: the laboratory measurements that decide whether the laser and the sail can work, and at what speed.

The mission

A 12 km laser array in the Schrödinger basin pushes 3.6 g probes to 20% of the speed of light in about 19 minutes. The burn starts slowly: about 11 of those minutes go to reaching 0.05c. Each probe is a StarChip, a whole spacecraft on a silicon die, towed by a stiffened 2.8 m sail. The array's ytterbium lasers sweep from 1.12 to 0.97 μm during each burn to follow the Doppler shift. Each probe then coasts for 21 years. It wakes near Proxima, photographs the system as it passes, and flashes about 0.55 Mbit home by laser, arriving about 25 years after launch. The same array receives the signal. Ten thousand probes fly, in 100 cohorts of 100, over about 12 years. First data would arrive around programme year 45.

The base on the Moon

Heavy lunar cargo landers deliver about 27,000 t from Earth, in about 270 landings. Lunar factories turn regolith into about 11.3 Mt of mirrors, flywheels, structure and heat storage. Only factory equipment, electronics, laser cores and other specialty parts come from Earth.

The cost

The reference study puts the whole programme at about \$574 billion. The P10–P90 range is about \$323–1,171 billion for economic inputs only, and \$361–1,568 billion with the sail's absorptance also unknown. Most of it pays for the lunar industrial base and the mirrors; the lasers are about 8%. The speed is a programme choice: the study's own rule would stop at 0.18c, about \$489 billion, because the last step buys earlier data at about \$36 billion a year. The estimate assumes solar power with flywheel storage. The helium-3 and fusion workstream is not in this cost.

The first questions

Can ytterbium lasers cover the band? At 0.20c they must sweep from 1.12 to 0.97 μm , exactly what the sail's grating allows. The margin is zero, and both ends are hard for ytterbium amplifiers (T30). **Can the stiffened sail be built?** It shows no flutter in the models, which keep its thin faces in tension by shaping the beam and limiting power early in the burn. But a 0.44 g/m² sandwich with a 15 nm back face has not been built or tested (T33, T36). **What does the sail absorb when hot?** Never measured at 1.1 μm (T5), and a bad answer now costs more: at 10⁶, 0.20c would be about \$1,217 billion. If ytterbium fails, the thulium design (0.12c, about \$502 billion) is the fallback.

The structure

Four gates. Each releases only the next step and can stop the programme. About 98% of the money is committed only after Gate D, and only after independent review.

THE ASK

\$160_M

Gate A · Measure · years 0–2

P10–P90 about \$140–200 M · 144 person-years, \$42 M equipment

Deliverables

- Absorptance and emissivity at 1.12–1.19 μm , up to 1,300 K, on grating coupons (T5)
- Ytterbium amplifiers across 0.97–1.12 μm , swept, at both edges (T30)
- Grating force by wavelength, especially at the rim; fabrication to ± 10 nm (T29)
- Sandwich coupons: flutter, and a 15 nm back face kept taut (T33, T36)
- LED-gimballed pod and dust erosion (T34, T31)
- Film creep, self-cleaning, micron fibres, start of ageing tests

Outcome

Go or stop, and the speed band. The data and pass criteria are published.

0.20_c

PLANNING SPEED
PROGRAMME CHOICE

\$574_B

REFERENCE COST
P10–P90 \$323–1,171 B

~\$14_B

SPENT BEFORE BUILD
DECISION

~45_{yr}

TO FIRST DATA

What has changed, and what it does not prove

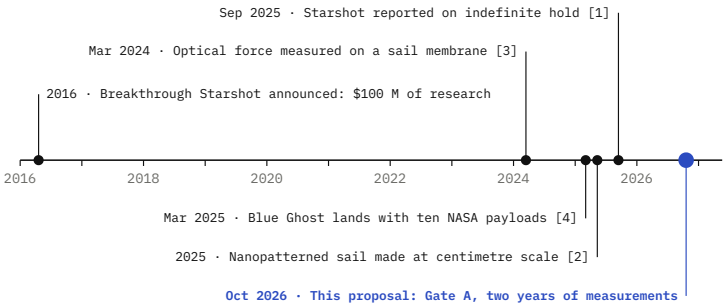
Breakthrough Starshot put laser-driven interstellar flight on the research agenda in 2016. In 2025 it was reported to be on indefinite hold [1]. In recent years, three pieces of evidence have moved. None shows that this mission works. Each makes a specific test cheaper and sharper.

EVIDENCE	WHAT IT SHOWS	WHAT IT DOES NOT SHOW
Force on a real sail membrane Michaeli et al., preprint, 2024 [3]	Optical force and laser heating can be measured together on a 50 nm silicon nitride membrane. Forces of about 80 fN were resolved at 100 W/cm².	Free flight, metre scale, or the gigawatt-per-square-metre intensities used here.
Nanopatterned sail at centimetre scale Norder et al., Nature Communications, 2025 [2]	A 60 × 60 mm, 200 nm thick reflector with over a billion nanoscale holes was made, at a reported 9,000-fold lower cost per m².	A 2.8 m silicon carbide dome, its optical properties when hot, or a tendon net. Different material and pattern.
Commercial lunar delivery NASA, March 2025 [4]	Firefly's Blue Ghost Mission 1 landed on 2 March 2025, carried ten NASA payloads and operated until 16 March.	Far-side industry, thousands of tonnes of cargo, or the transport price assumed here. It landed on the near side.

A design with fewer unknowns

The study behind this paper replaced each ideal assumption with physics: real wave optics, thermal limits, weak emission from thin films, flexible lines, realistic beams, a sail that flutters. The design that results has a stiffened, slimmed sail and heat-aware beams. It uses ytterbium lasers near 1 µm and, because their beams spread half as fast, a smaller 2.8 m sail, reaching 0.20c. The shaped light is kept under the sail's heat limit, 8.8 GW/m² at the rim at launch, and every beam is held to the power at which the sail's thin faces stay in tension. The burn therefore starts slowly, and the estimate is about \$574 billion (P10–P90 \$323–1,171 billion) at 0.20c. A thulium design at 2 µm, 0.12c at about \$502 billion, is the fallback.

The photonics are ready to test, not proven. The remaining unknowns are few, and most can be measured in a laboratory.



WHAT HAS MOVED SINCE 2016

DATES FROM THE SOURCES CITED

What does not follow

Nothing here justifies construction. It justifies a bounded measurement programme with published pass criteria. A negative result is useful too. It stops a much larger spend early.

2_{y1}

GATE A: LABORATORY MEASUREMENTS, ABOUT \$160 MILLION

29

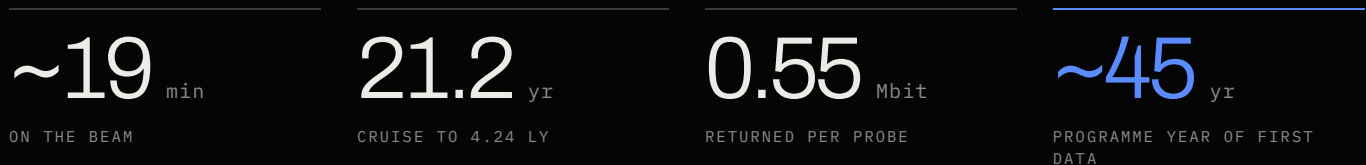
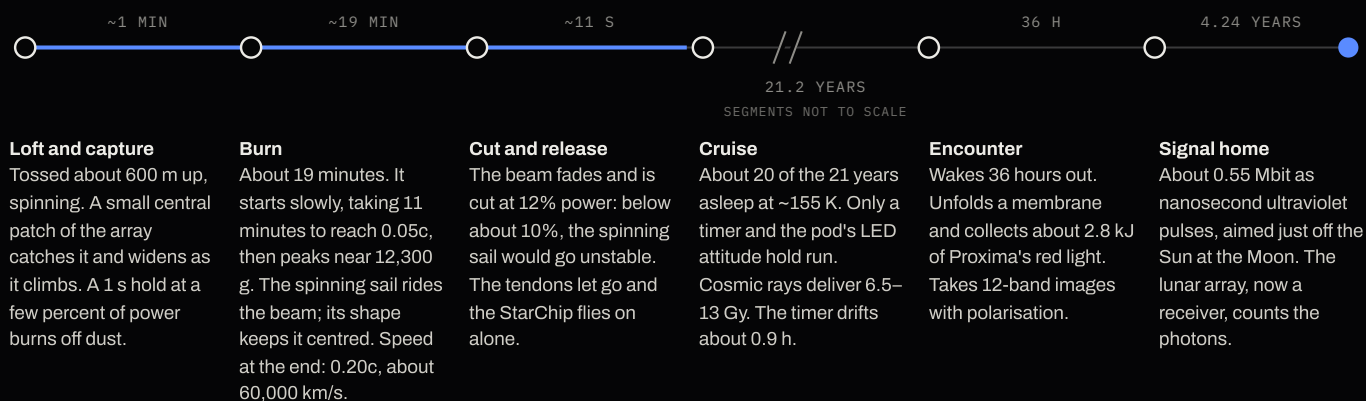
STARSHOT ENGINEERING CHALLENGES ANSWERED IN THE STUDY FOR THIS DESIGN

0

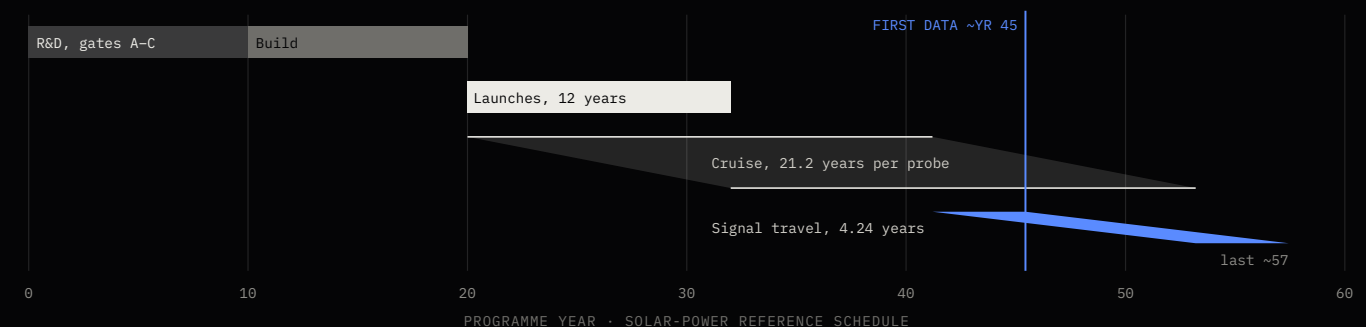
LASER-BAND MARGIN AT 0.20C: THE YTTERBIUM TEST T30 SETS THE TOP SPEED

One probe, from launch to first data

A probe spends about 19 minutes on the beam and 21 years coasting. Its pictures take another 4.24 years to reach the Moon, so data arrives about 25 years after launch. The programme reaches first data around year 45 because the array must be researched and built first.



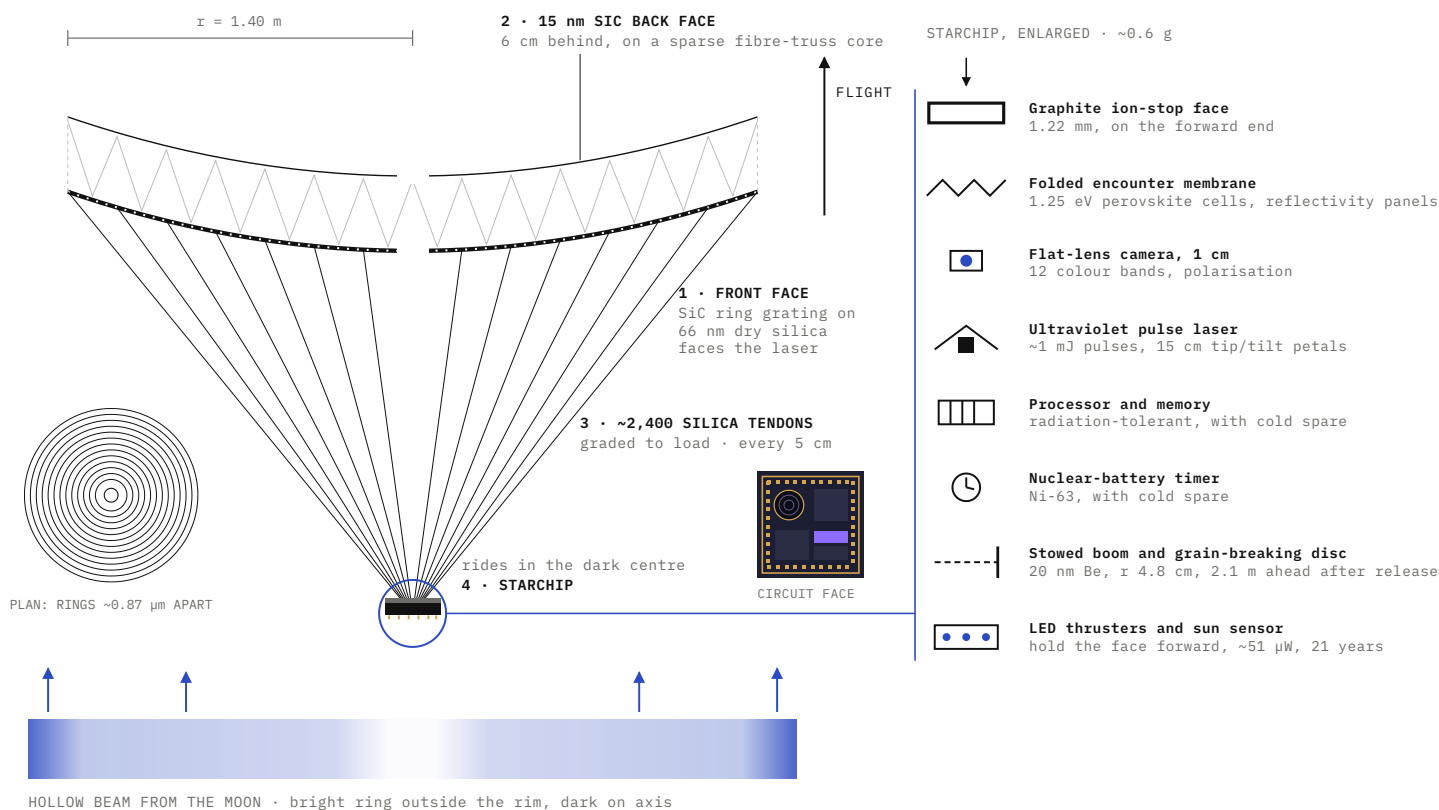
THE PROGRAMME, TO SCALE



The helium-3 energy workstream has its own critical path, not yet scheduled. Year 45 applies to the solar-and-storage reference at 0.20c (about year 48 at 0.18c, about year 60 for the thulium fallback at 0.12c). Durations are counted from programme start, not calendar dates.

Three and a half grams, mostly sail

A stiffened, curved mirror 2.8 m across, a web of glass fibres and a StarChip of about 0.6 g: 3.56 g at launch. After the burn the StarChip drops the sail, unfolds a dust disc ahead of itself and flies on alone.



CONCEPT EXPLODED AND NOT TO SCALE

THE STARCHIP SITS ABOUT 0.7 M IN FRONT OF THE DOME, ON AXIS

SAIL 2.68 G · 0.442 G/m²

STARCHIP ~0.6 G AND TENDONS ~0.27 G · TOTAL 3.56 G

1 · The front face

Silicon carbide rings 0.87 μm apart and 0.23 μm tall on a 66 nm film of dry silica: a broadband reflector for ytterbium light, stable while the sail sees about 1.12–1.19 μm. Its push changes with the light's angle, which holds the sail on the beam; the silica radiates the heat. The rings must be made to about ±10 nm, or an absorbing dark mode enters the band. The dome is 1.40 m in radius, bulges toward the laser, and has a small central hole.

2 · The back face and core

A sail is limited by the light each gram can take, so the back face, which sheds no heat, is just 15 nm of silicon carbide, 6 cm behind on a sparse fibre truss. The pair is stiff in bending (~11 N·m radially, ~18 N·m around the hoop). A ~1 μm beam spreads half as fast as a 2 μm one, so the best sail is small and light: 2.8 m across, 0.442 g/m², 2.68 g, spun at 330 rad/s to keep the faces taut. It shows no flutter in the models.

3 · The tendons

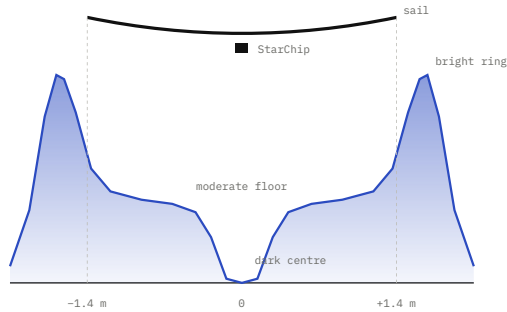
About 2,400 silica fibres, a few micrometres thick and up to ~1.6 m long, sized ring by ring to their load (0.27 g, ≤1.82 GPa). Attached every 5 cm, they keep each panel flat to within 3°.

4 · The StarChip

A silicon die with camera, laser, processor, memory and timer, built to survive 21 years. At 0.20c a dust shield would be heavy, so the pod points itself: a boom unfolds a 20 nm beryllium disc 2.1 m ahead, and LED thrusters on ~51 μW keep its 1.22 mm graphite face behind it, 65 mg in all.

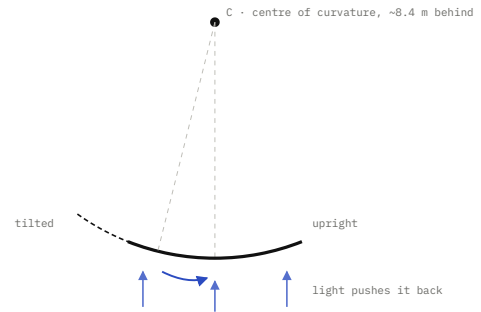
Nineteen minutes on the beam

A sail pushed at up to 12,300 g will slide off the beam, flip or flutter unless something holds it. Nothing on the probe steers it. The sail's shape, its stiffness and the beam's shape do the work.



A · BEAM INTENSITY ACROSS THE SAIL

SCHEMATIC



B · TILT: A PENDULUM HANGING FROM C

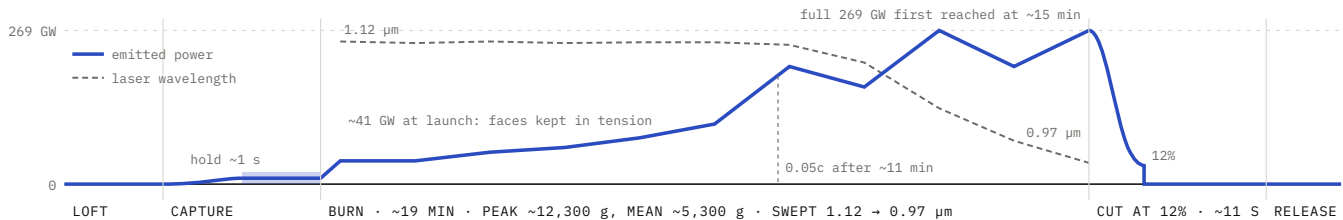
SCHEMATIC

Sideways drift

A dome curved toward the light tends to slide off a centre-bright beam. So the array makes a hollow beam: a moderate floor across the sail, a bright ring just outside its rim, dark on the axis. If the sail drifts, its edge meets the ring and is pushed back. Amplitude shaping leaves no part of it dim, and keeps the added light under the sail's local heat limit.

Tilt

The dome's centre of curvature sits far behind the sail, about six sail radii. Light pushes each patch of the dome along its normal, and all normals pass through that point. So the dome behaves like a pendulum: tilt it, and the push rights it, but only while the sail sees its stable band, about 1.12–1.19 μm .



C · BEAM POWER THROUGH ONE LAUNCH

STUDY BURN PROFILE · LOFT, CAPTURE AND FADE NOT TO SCALE

Following the Doppler shift, with no margin

As the sail speeds away, the light it sees shifts redder: at 0.20c, light sent at 1.12 μm arrives at 1.37 μm . The grating holds the sail only at about 1.12–1.19 μm , so the array sweeps from 1.12 down to 0.97 μm , exactly the width 0.20c needs. Both ends are hard for ytterbium; each 1% of band lost costs ~0.01c.

A slow start: tension, then heat

At the first wavelengths the grating barely pushes at the sail's rim, which is dead weight until about 0.05c and has little heat margin for extra light. So every beam is held to the power at which the sail's thin faces stay in tension: about 640 g at launch, with 11 of the 19 minutes spent reaching 0.05c. Then the heat cap binds, at 8.8–15.1 GW/m^2 .

The light delay

The round trip reaches ~175 s, too late for the Moon to correct. The sail holds itself if beam-centre jitter stays $\leq 3.0 \times 10^{-16} \text{ rad}/\sqrt{\text{Hz}}$: ~3.6 $\text{pm}/\sqrt{\text{Hz}}$ of correlated tilt across the 12 km array.

Flutter, and the stiffened sail

A thin-film sail flutters destructively; no passive thin-film fix worked.

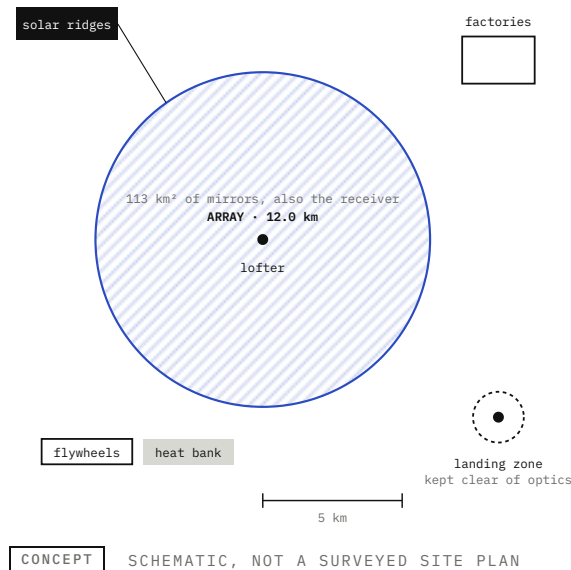
The stiffened sail shows no flutter in the models, linear and nonlinear, on the beams the burn uses. The models keep its thin faces in tension by shaping the beam and limiting power early in the burn; the 10 of 1,178 beam settings that fail are barred. The check has three limits (page 13): the first ~0.015c rests on a simpler, smooth model; the spin margin is 1.15 $\times$, not the usual 1.2 $\times$; and real tendons, unlike the model's, cannot be re-tuned during the burn. Not yet built or tested (T33, T36).

Clean start, clean cut

A one-second low-power hold burns off dust. The beam fades and is cut at 12% power: below ~10%, a sail spinning at 330 rad/s goes unstable. None of it has flown.

An industrial base that builds a laser

The array sits in the Schrödinger basin, near the lunar south pole on the far side. Proxima Centauri never sets there: it circles 30–60° above the horizon. Earth never rises, so the array cannot be aimed at Earth.



Launch windows

The array launches only when Proxima is at least 50° high, about 31% of the time. Lower down, the flat array looks too foreshortened from the star. This is why the campaign takes 12 years and the solar plant is sized at 52 GW.

The array

A filled disc 12.0 km across, about 113 km² of mirrors made from lunar glass. About 90 million ytterbium fibre amplifiers of roughly 3 kW each emit up to 269 GW, swept from 1.12 to 0.97 μm during each burn. One master laser sets their phase. Each amplifier has its own electronic delay, so light from emitters kilometres apart arrives at the sail in step, to about a picosecond. Each emitter's polarisation is fixed by its position, which makes the whole beam azimuthally polarised. Switched to receiving, the same mirrors catch the probes' messages; they exceed the separate 95 km² receiver requirement.

The industry

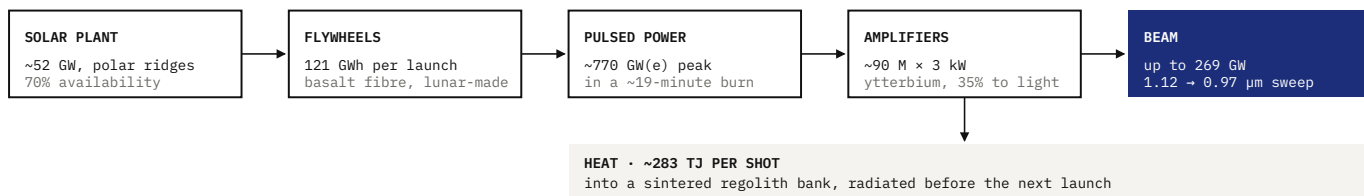
About 11.3 Mt of mirrors, mounts, flywheels, heat bank, cabling and structure are made on the Moon from regolith. About 27,000 t comes from Earth: factory equipment (13,500 t) and laser, optics, storage and power parts. At about 100 t per landing that is roughly 270 heavy-cargo landings. Transport costs about \$267 billion, spread through the cost lines.

Starship is our planning choice for this cargo, not a finding of the study. The plan is not tied to it; other heavy landers can carry the same cargo as they mature. No SpaceX partnership or contracted delivery is implied.

Why lunar industry

Shipping 11.3 Mt from Earth is not credible. The lunar base is the largest cost line, about \$242 billion. The lunar transport price (33% of the cost spread), the factories' productivity (31%) and the sail's absorptance (21%) are the largest uncertainties. A pilot factory in Gate C measures the real productivity.

ENERGY PER LAUNCH • SOLAR-AND-STORAGE REFERENCE



NOT COSTED

Helium-3 and fusion

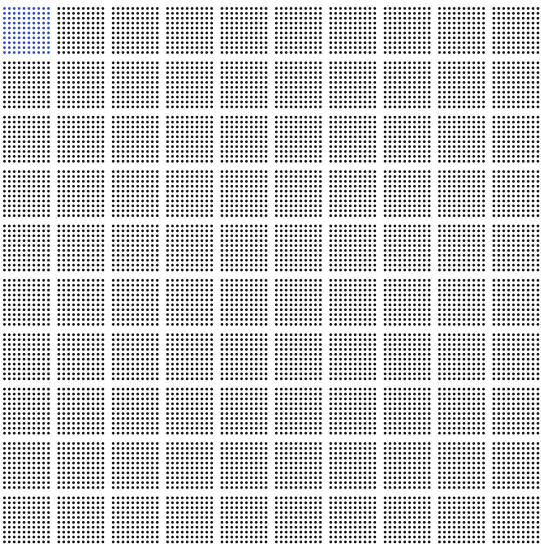
Development workstream

We propose lunar helium-3 and fusion as the long-term energy path. It is a development workstream, not a study result, and not costed. There is no measured ore grade or net-electric reactor. The \$574 billion reference (P10–P90 \$323–1,171 billion) uses solar power and flywheels. For scale: 121 GWh per launch needs a 52 GW plant, before mining, plant and factory loads.

Before a helium-3 facility could be chosen, it would need its own gate: measured resource grade and recovery, energy spent per kilogram recovered, a net-electric reactor demonstration, and a full delivered cost.

Why ten thousand probes

A single probe is cheap: all 10,000 cost about \$2 billion. Many are needed because the planet's exact position is uncertain and many probes will fail during the long sleep. Numbers make up for both, but at 0.20c only just.



Cadence and cohorts

About 10,000 launches over 12 years, one every 10 hours on average, only while Proxima is at least 50° high (31% of the time). The probes are grouped into 100 cohorts of 100. A cohort is an operational unit for manufacture, qualification, launch and tracking, about six weeks of launches. Cohorts do not fly in formation.

Aiming the swarm

Separately, the study aims the swarm as a 100 × 100 pattern about 3×10⁻⁸ rad wide. The pattern covers the uncertainty in the planet's position, so that about 54% of surviving probes pass within 0.01 AU of it. The aim corrects for the Moon's own motion, Proxima's motion during the flight, and the bending of the path by the Sun's gravity, which must use relativistic equations of motion. The aiming budget closes, at 2.1×10⁻⁸ against 3×10⁻⁸ rad, if the array knows its beam axis against the stars to about 3 mas.

Survival and dust

The biggest modelled loss is the 20-year sleep. With spare electronics, a spare timer and redundant actuators, the study expects 63% of probes to work at encounter (range 25–88%). At 0.20c a forward dust shield would be heavy and nothing passive keeps it forward, so the pod points itself (page 6). That is unvalidated (T34): the attitude must hold for 21 years on ~50 μW, and the 2.1 m boom must deploy after a burn that peaks near 12,300 g. The light probe leans hard on this pod, so the fallbacks are costly: a film enclosure around it (6.29 g probe, about \$1,008 billion) or an armoured spinning rim (about \$1,319 billion).

Planetary protection

The chance that a probe strikes a planet is about 10⁻⁶ each. Aiming the pattern off the planet's centre cuts that about a hundredfold.

FROM LAUNCH TO DATA · STUDY VALUES

CASE	PROBES WORKING AT ENCOUNTER	WORKING	PER PROBE	SWARM RETURN
Launched		10,000	—	—
Optimistic		~8,800	0.55 Mbit	~4.8 Gbit
Nominal		~6,300	0.55 Mbit	~3.5 Gbit
Pessimistic		~2,500	0.55 Mbit	~1.4 Gbit

What the data would contain

Twelve-band images and polarimetry of the planets' atmospheres and surfaces, their orbits, the star's flare environment and the dust between them. Each probe chooses what to keep. This is a targeted set of images and spectra, not video.

Why not fewer: the margin is thin

A faster fly-by harvests less starlight, so each probe returns less. In the pessimistic survival case the science case needs about 9,700 probes for a 10% margin; 10,000 give only about 1.04× that. A larger receiver or a higher pulse-position order would widen it. Neither is yet traded.

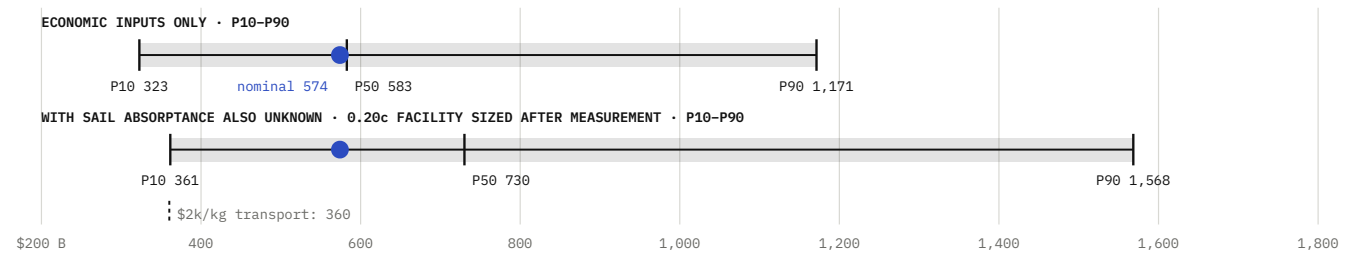
About \$574 billion, and what moves it

The reference estimate is about \$574 billion, with a P10–P90 range of \$323–1,171 billion. It is a model result, not a quote. We present it as one coordinated investment in three things: photonics, the space economy on the Moon, and the mission itself. It covers the lunar industry, the array, power, research, engineering, 12 years of launches, 21 years of caretaking and reception. Most of the money goes into making mirrors and flywheels from the Moon itself.

COST LINE	INVESTMENT IN	\$ B	SHARE	RELATIVE SIZE
Lunar industrial base (factories for ~11.3 Mt)	Lunar industry	242	42%	
Optics: 113 km² of mirrors and mounts	Photonics	79	14%	
Operations: build, launches, caretaking, reception	The mission	57	10%	
Pulsed power	Lunar power	54	9%	
Lasers (269 GW, ytterbium)	Photonics	47	8%	
Energy storage (flywheels)	Lunar power	28	5%	
Solar plant (52 GW)	Lunar power	21	4%	
Other hardware	The mission	18	3%	
Research and development (Phases 0–2)	The mission	15	3%	
Engineering (Phase 3)	The mission	10	2%	
Probes (10,000)	The mission	2	<1%	
Total, nominal		574	100%	

By group: photonics (optics and lasers) about \$126 B, 22%. The space economy about \$345 B, 60%: lunar industry \$242 B and lunar power (pulsed power, storage, solar) \$103 B. The mission itself (operations, other hardware, research, engineering, probes) about \$102 B, 18%. Shipping Earth-built parts to the Moon, about \$267 B at \$10,000/kg, is inside these lines, not a line of its own. The lines sum to the total, within rounding. The study prices the build; it has not estimated the returns to photonics or the space economy.

THE RANGE



The first range varies the economic inputs at the fixed 0.20c design. The second also varies the unmeasured sail absorptance, with the 0.20c facility sized after the measurement, as planned. The nominal is the estimate at central inputs. It is not a median: skewed inputs put both P50s above it.

33 %

LUNAR TRANSPORT PRICE
\$1K–20K/KG · BASE \$10K/KG

31 %

LUNAR FACTORY PRODUCTIVITY
MEASURED IN GATE C

21 %

SAIL ABSORPTANCE
MEASURED IN GATE A

9 %

FACTORY EQUIPMENT PRICE
SHIPPED FROM EARTH

Share of the cost spread from each input. These four account for about 94%. The laser price accounts for about 0.3%. With the smaller sail, absorptance matters far more than before: at 10°, 0.20c would cost about \$1,217 B. The speed is a choice on top of this range: at the same inputs, 0.18c costs about \$489 B and 0.12c about \$371 B.

Can the laser cover the band, and the sail take the light?

Gate A answers three questions first. Can ytterbium amplifiers hold efficiency and phase at both ends of their band? Can the stiffened sail be built, be kept taut by the beam alone, and stay free of flutter? What does it absorb at 1.1 μm when hot? None has been measured.

A laser band with zero margin

From rest to 0.20c the light the sail sees stretches by a factor of about 1.154, and the grating is stable over only part of that. The laser must cover the rest: 1.12 to 0.97 μm is a ratio of 1.155. Ytterbium fibre amplifiers work best near 1.03–1.08 μm . At 976 nm they need very high inversion; at 1.12 μm gain is weak and noise at shorter wavelengths competes. Each 1% of band lost costs about 0.01c: an amplifier that stops at 0.98 μm gives about 0.19c. If ytterbium fails more broadly, the thulium design (0.12c, about \$502 billion) is the fallback. Test T30 decides.

Heat and tension

At ~1 μm , free-carrier heating is about three times weaker than at 2 μm and the grating concentrates the field about three times less. Hot silicon carbide no longer runs away; the 1,300 K ceiling sets a thermal cap of 8.8–15.1 GW/m², which binds through the middle of the burn. Early on, a second limit binds instead: every beam is held to the power at which the sail's thin faces stay in tension. The thermal cap assumes an absorptance of 3 parts in 10 million at room temperature, never measured for this grating (T5). With the smaller sail a bad answer costs more: absorptance is now 21% of the cost spread.

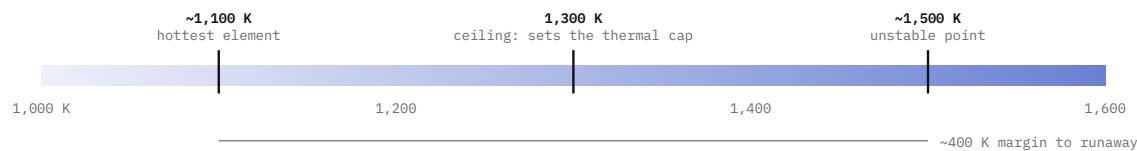
The rule that turns the results into a design

The facility is sized only after the measurements. The study picks the speed with a fixed rule (R49): pay no more than about \$27 billion for each year that data arrives earlier. At the planning absorptance, each year costs about \$4 billion from 0.10c to 0.12c, rising to \$17 billion from 0.16c to 0.18c and \$36 billion from 0.18c to 0.20c. So the rule picks 0.18c, at about \$489 billion. **The plan is 0.20c by programme choice:** about \$85 billion buys about 2.4 years of earlier data.

When to stop

If hot absorptance at 1.12–1.19 μm is above a few parts per million, the thermal cap falls so far that cost rises steeply at any interstellar speed. Then the programme stops, or redirects to a new material search or a solar-system mission. It also stops or slows if the sandwich flutters, cannot be kept taut or cannot be built near 0.44 g/m², or if the grating's absorbing dark mode moves into the band at the tolerance that can be made.

SAIL TEMPERATURE AT THE THERMAL CAP • STUDY VALUES



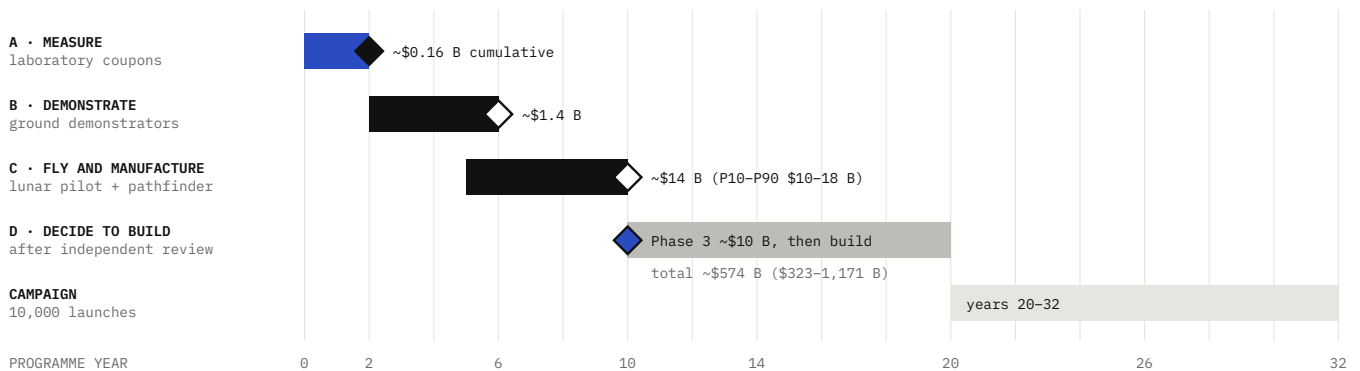
THE DECISION GATE A FEEDS • PROGRAMME COST, \$ BILLION

MEASURED ABSORPTANCE (ROOM TEMPERATURE)	0.10C	0.12C	0.14C	0.16C	0.18C	0.20C	RULE PICKS	PLANNED
1×10^{-7}	342	371	401	439	485	571	0.18c	0.20c
3×10^{-7} • planning	342	371	402	441	489	574	0.18c	0.20c, if T30 passes
1×10^{-6}	364	416	517	649	820	1,217	0.14c	Decide at Gate D
$\gg 10^{-6}$	—	—	—	—	—	—	—	Stop or redesign
First data, programme year	~67	~60	~55	~51	~48	~45		

Ytterbium system; each cell re-sizes the whole facility. Up to 3×10^{-7} absorptance barely moves the cost. At 10^{-6} the thermal cap is much lower: the 0.20c array grows to 28.5 km and the cost more than doubles. The top speed is set by the laser band (T30). Source: Baseline Z speed trade, Revision BA.

Four gates, each able to stop the work

Spend little until the measurements that decide the programme's shape are done. Each phase retires the largest remaining uncertainty for the least money. A pass releases only the next phase, under its own budget.



GATES ARE DECISION POINTS (◆). ABOUT 98% OF THE MONEY IS COMMITTED ONLY AFTER GATE D.

ROADMAP VALUES

GATE	WHAT MUST PASS	WHAT STOPS OR REDIRECTS IT
A • Measure yrs 0–2 ~\$160 M	Room-temperature absorptance $\leq 3 \times 10^{-7}$ at 1.12–1.19 μm , with growth when hot as modelled (T5). Emissivity ≥ 0.008 at 1,100 K; film creep $< 1\%$ at 1,050–1,300 K. Specks down to $\sim 0.08 \mu\text{m}$, bonded ones included, burn off in the low-power hold. Grating force at each wavelength, above all at the rim on the first wavelengths, and fabrication to $\pm 10 \text{ nm}$ with the dark mode out of band (T29). Ytterbium amplifiers efficient and in phase across 0.97–1.12 μm , both edges, while swept (T30). Sandwich coupons with a 6 cm core, their faces held in tension by the light alone, show no flutter (T33); a 15 nm back face stays taut with little tension to spare (T36). The LED-gimballed pod's disc, boom and attitude hold (T34) and dust erosion (T31) as modelled.	Hot absorptance above a few $\times 10^{-6}$; emissivity far below model; grating band or dark mode off model. Ytterbium cannot cover the sweep: fall back to thulium (0.12c, ~\$502 B). The sandwich flutters or cannot be built near 0.44 g/m^2 : a heavier sail and a slower speed.
B • Demonstrate yrs 2–6 ~\$1.2 B	A 3 kW coherent ytterbium amplifier across 0.97–1.12 μm at design efficiency, held in phase through a full-burn sweep. A $\sim 1,000$ -emitter array that makes hollow beams with phase noise $\leq 0.2 \text{ rad}$ and timing $\leq 1 \text{ ps}$, and holds beam size to $\pm 5\%$. A sail coupon riding a beam in vacuum with a control delay of minutes, within $\sim 20\%$ of the model. A 1:10 dome that deploys by spin without tangling.	Coupon stability far from model; phase noise not held; kilowatt amplifiers stall at either band edge. Fallbacks: a narrower sweep and a slower speed (~ 0.18 – 0.19c); thulium at 0.12c.
C • Fly and manufacture yrs 5–10 ~\$12.6 B	A lunar industry pilot (about 81 t shipped) measures factory productivity. Its glass and fibre lines supply a lean pathfinder: a 100 m, 100 MW ytterbium array flying sails of 8.5–50 cm at up to $\sim 430 \text{ km/s}$ (upper bounds). At least 20 flights per size, $\geq 90\%$ riding stably; the smallest hold the thermal cap below 1,300 K. Productivity within $\sim 2\times$ of model.	Flight stability or the industry pilot fails. About \$14 B spent by then; roughly 98% not yet committed.
D • Decide to build yrs 10–20	Independent technical, economic, operational and governance review. Final facility sizing from measured data. At the planning absorptance the rule picks 0.18c; 0.20c is a programme choice that needs the whole ytterbium band. Phase 3 engineering, about \$10 B, then the build, over about a decade.	Authorise, redirect, defer or stop. No automatic escalation.

Phase budgets are parametric estimates, not quotes; the new tests T29–T36 are carried in contingency until costed bottom-up. Large research programmes often overrun by more than the contingency used. The lunar transport price (33% of the cost spread) is set by the launch market; factory productivity (31%) and the sail's absorptance (21%) are the largest drivers the programme can measure itself, in Gates C and A.

What could still stop it

Ranked in the order they should be tested. Each could change the design by hundreds of billions of dollars, or end it.

#	RISK	WHY IT MATTERS	RETIRED BY	FALLBACK
1	Ytterbium amplifiers across 0.97–1.12 μm	About 90 million coherent 3 kW amplifiers, swept in every burn. Zero band margin at 0.20c; both edges are hard.	Band test (T30, A), amplifier builds (B)	Narrower band, ~0.18–0.19c; thulium at 0.12c, ~\$502 B.
2	The stiffened sail	No flutter in the models, which keep its thin faces in tension; that check has three limits (below). Unbuilt: a 15 nm back face on a 6 cm core at 0.44 g/m ² , ~15 GW/m ² , ~12,300 g.	Flutter and fabrication coupons (T33, T36, A)	A stiffer, heavier sandwich: a slower speed.
3	Hot absorptance at 1.12–1.19 μm, emissivity, contamination	Never measured. Now 21% of the cost spread: at 10 ⁻⁶ , 0.20c costs ~\$1,217 B. Specks above ~0.08 μm could start runaway heating.	Coupon and contaminated-coupon tests (T5, T28, A)	Slower speed from the decision table. Well above 10 ⁻⁶ : stop or redesign.
4	Grating fabrication and force by wavelength	Rings held to ± 10 nm and $\pm 1\%$, or an absorbing dark mode enters the band. The tilt response and the rim's weak push are modelled, not measured.	Coupon force tests (T29, A)	Retune the grating; narrower band, slower speed.
5	Beam jitter and the fade	Beam-centre jitter $\leq 3.0 \times 10^{-16}$ rad/ $\sqrt{\text{Hz}}$ (~3.6 pm/ $\sqrt{\text{Hz}}$); phase noise ≤ 0.2 rad, beam size $\pm 5\%$, cut at 12% power.	1,000-emitter array (B), pathfinder (C)	A passive damper on the sail (~4 $\times$ relief).
6	Dust: the LED-gimballed pod	21-year attitude hold on ~50 μW ; boom stowed through a ~12,300 g burn; grain breaking at 0.20c. Unvalidated, and the light probe leans on it.	Pod and grain-breaking tests (T34), erosion (T31)	Film enclosure (6.29 g, ~\$1,008 B) or armoured rim (~\$1,319 B).
7	Thin science margin	The pessimistic case needs ~9,700 of the 10,000 probes: only ~1.04 $\times$ margin.	Encounter model; receiver trade	Larger receiver, higher pulse-position order, more probes.
8	Tendon net and core	About 2,400 graded silica fibres and a 6 cm truss, made, packed and deployed without tangling.	Fibre tests (A), 1:10 deployment (B), 50 cm sails (C)	Coarser spacing; sapphire at hot joints.
9	A 20-year sleep	Dormant electronics and deployment reliability dominate losses.	Ageing tests from A through C	More redundancy, at some probe mass.
10	Lunar industry, transport price and launch window	Together about 64% of the cost spread. Launches only when Proxima is $\geq 50^\circ$ high, 31% of the time, leave less slack in the 12-year campaign.	Industry pilot (C); external launch market	Higher cost. At \$2k/kg the total falls to ~\$360 B.
11	Helium-3 and fusion NOT COSTED	The proposed energy path has no demonstrated reactor or resource data.	Separate workstream gate	Solar and flywheel storage, as in the reference.
12	Governance	A 269 GW array can reach anything in cislunar space in its sky.	International framework before Gate D	No build without it.

Three limits of the flutter check

- For the first ~0.015c the detailed, faceted model cannot represent a tension-only sail at such low loads. That stage rests on a simpler, smooth model; the nonlinear run there lets the faces carry compression.
- The spin margin for staying in tension is 1.15 $\times$ at mid-burn, not the customary 1.2 $\times$, which would need 346 rad/s.
- The model re-chooses the tendon loads at each stage. Real tendons have one set of lengths for the whole burn. This has never been checked.

Other open questions

- Independent reruns of the optics, structure, heat and cost models.
- Thrust lost to filling the beam at the first wavelengths; the core is sized only roughly.
- Whether 0.20c is worth ~\$36 B a year of earlier data; the rule picks 0.18c.
- A financing convention, a site survey, an integrated schedule and a minimum science product.
- Receiver size against data return; beams for the elliptical array; a helium-3 energy model.

Independent, and built on a public idea

GUY is independent. This proposal is not endorsed by Breakthrough Initiatives and does not restart, continue or take over Breakthrough Starshot. It builds on the public research agenda that Starshot helped create.

What we take from Starshot

The idea of gram-scale probes pushed by a large laser array, the name StarChip for such a probe, and a public list of 29 engineering challenges. This proposal improves on those ideas, and the design study answers each of the 29 for this architecture.

What is different

As press coverage summarised it, Starshot aimed to send gram-scale probes at a fifth of light speed, reaching Alpha Centauri within about 20 years [1]. This proposal now plans a similar speed, 0.20c, but reaches it with a heavier, stiffened sail and a much longer burn. It moves the laser to the Moon, flies 10,000 probes, and stages every commitment behind a measurement. The speed is a programme choice: the study's own cost rule would stop at 0.18c.

Status of Starshot

Scientific American reported in September 2025 that the effort, announced with \$100 million of research funding, was on indefinite hold, without a formal closing announcement [1]. We rely on that reporting, not on an official notice.

ELEMENT	STARSHOT, AS PUBLICLY DESCRIBED	THIS PROPOSAL
Target	Alpha Centauri system	Proxima Centauri, 4.24 ly
Speed	About 0.2c	0.20c planned, a programme choice (the study's rule picks 0.18c); the laser band has zero margin
Laser site	Earth-based array	Lunar far side, Schrödinger basin; ytterbium, ~1 µm
Sail	Metre-scale, nanometre-thin	SiC ring-grating dome, 1.40 m radius, stiffened as a sandwich with a 15 nm SiC back face 6 cm behind; tendon net
Stability	Open research question	Curved dome in a hollow beam shaped in amplitude and phase, wavelength swept to track the Doppler shift. The stiffened sail shows no flutter in the models; not yet built or tested (T33, T36)
Probes	Many gram-scale probes	10,000, in 100 cohorts of 100
Funding path	\$100 M research programme	Four gates; ~\$160 M first

The left column summarises public descriptions only. It is not an official Breakthrough statement.

GOVERNANCE

A laser that cannot see Earth

From the far side, Earth never rises. That is a useful geometric limit. It is not a complete safety case. The array can reach anything in cislunar space that is in its sky.

Dual use

A 269 GW array could also nudge small asteroids. That makes it the strongest planetary-defence tool yet proposed, and the project's sharpest governance question. International control and verification are required, not optional.

Safeguards to build first

Independently verifiable pointing limits, beam-inhibit rules, coordination with other space operators, controlled firing authority and auditable records. Planetary protection and effects on astronomy need specialist review. No regulatory approval is claimed.

Review at every gate

We propose independent scientific and engineering review at each gate, a separate cost and schedule review, and publication of dissenting views and the evidence used to resolve them.

Institutions that last

First data arrives decades after launch. The plan must fund data standards, custodianship, operations and succession, not only hardware.

Value if it stops

A stopped programme still leaves hot-sail measurements, coherent-laser and beam-control methods, and lunar manufacturing data. Any redirection needs its own case.

References and sources

External sources give context and specific experimental results. Mission numbers and test targets come from the Lunar Starshot design study, Baseline Z (Revision BA), which is not published. Online sources were checked on 25 September 2026.

External references

- [1] Scoles, S. (2025). The quiet demise of Breakthrough Starshot, a billionaire's interstellar mission to Alpha Centauri. *Scientific American*, 16 September 2025.
<https://www.scientificamerican.com/article/the-quiet-demise-of-breakthrough-starshot-a-billionaires-interstellar/>

- [2] Norder, L., Yin, S., de Jong, M. H. J., Stallone, F., Aydogmus, H., Sberna, P. M., Bessa, M. A. & Norte, R. A. (2025). Pentagonal photonic crystal mirrors: scalable lightsails with enhanced acceleration via neural topology optimization. *Nature Communications* 16, 2753.
<https://www.nature.com/articles/s41467-025-57749-y>

- [3] Michaeli, L., Gao, R., Kelzenberg, M. D., Hail, C. U., Merkt, A., Sader, J. E. & Atwater, H. A. (2024). Direct radiation pressure measurements for lightsail membranes. arXiv:2403.00117.
<https://arxiv.org/abs/2403.00117>

- [4] NASA (18 March 2025). NASA science continues after Firefly's first Moon mission concludes. News release.
<https://www.nasa.gov/news-release/nasa-science-continues-after-fireflys-first-moon-mission-concludes/>

- [5] NASA's Scientific Visualization Studio (2019). CGI Moon Kit. Source of the lunar texture on the cover.
<https://svs.gsfc.nasa.gov/4720>

Status of the technical work

This paper summarises the study. It does not reproduce its optical optimisation, structural dynamics, thermal model or cost Monte Carlo. Before Gate A closes, we propose a versioned, reproducible technical package with independent reruns and unit checks.

Reconciled numbers

Swarm return of ~3.5 Gbit is 63% of 10,000 probes working, at ~0.55 Mbit each. The cost lines sum to the ~\$574 B total (P10–P90 \$323–1,171 B) within rounding; transport of Earth-built parts (~\$267 B) sits inside them. The website's animations are explanatory and establish no technical claim; beams shown there visualise invisible infrared light.

Reference data

Baseline Z, Revision BA, planning case: 0.20c (a programme choice) at a room-temperature absorptance of 3×10^{-7} . Study values, rounded.

MISSION	VALUE	LAUNCH AND FACILITY	VALUE
Cruise speed	0.20c (~60,000 km/s)	Beam power	269 GW
Distance to Proxima Centauri	4.24 ly	Ytterbium sweep	1.12 → 0.97 μm
Cruise; flashes home after	21.2 yr; ~25 yr	Array (also the receiver)	12.0 km, 113 km ²
Dormancy, pod temperature	~19.7 yr, ~155 K	Amplifiers	~90 M × 3 kW
Energy harvested	~2.8 kJ	Burn; distance at end	~19 min; ~0.14 AU
Data per probe	~0.55 Mbit	Slow start: time to reach 0.05c	~11 min
Swarm return	~3.5 Gbit (1.4–4.8)	Acceleration, peak / mean	~12,300 / ~5,300 g
Probes working at encounter	63% (25–88%)	End of burn	Cut at 12% power
Pessimistic case needs	~9,700 probes (~1.04×)	Thermal cap, sail frame	8.8–15.1 GW/m ²
Aim error, total / budget	2.1 / 3×10^{-8} rad	Hottest element (thermal cap)	~1,100 K
Survivors within 0.01 AU	~54%	Beam-centre jitter allowed	$\leq 3.0 \times 10^{-16}$ rad/√Hz
First data	~programme yr 45	Electricity; heat per launch	121 GWh; ~283 TJ
		Solar plant	~52 GW, 70% availability
PROBE	VALUE	Proxima elevation; window	30–60°; ≥ 50°, 31%
Total mass	3.56 g	Probes, campaign length	10,000, ~12 yr
Sail mass, areal density	2.68 g, 0.442 g/m ²	Lunar products	~11.3 Mt
StarChip, tendons	~0.6 g, ~0.27 g	Imports from Earth	~27 kt, ~270 landings
Dome radius	1.40 m		
Front face	SiC grating, 66 nm silica	COST	VALUE
Grating period; stable band	0.866 μm; 1.12–1.19 μm	Nominal (not a median)	~\$574 B
Back face	15 nm SiC, 6 cm behind	P10–P90, economic only	\$323–1,171 B
Bending stiffness, radial / hoop	~11 / ~18 N·m	P10–P90, with absorptance	\$361–1,568 B
Tendons, graded	~2,400, ≤ 1.82 GPa	At \$2k/kg lunar transport	~\$360 B
Spin during the burn	330 rad/s	Transport, inside the lines	~\$267 B
Flutter	None in models; untested	Rule's pick	0.18c, ~\$489 B
Thin faces during the burn	In tension (models)	Thulium fallback	0.12c, ~\$502 B
Dust protection	LED pod, 65 mg	Spend to Gate A / B / C	~\$0.16 / 1.4 / 14 B
		Helium-3 and fusion	Not costed