AESTRYN RESEARCH

Historical Photon Recovery

A dual-track program for independent Earth observation and frontier historical retrieval

Building a physically independent visual archive of Earth, with arbitrary historical retrieval as the ultimate objective

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Abstract

Aestryn's ultimate mission is to make history observable. Its operating thesis is narrower and testable: develop technology to preserve and recover visual information across time by exploiting the finite propagation of light. The program is divided into Aestryn Archive, which uses known physics to build extreme-imaging systems and outward-moving independent observers, and Aestryn Retrieval, which investigates whether any future spacetime-access mechanism could reach photons emitted before the network existed. The progression is deliberate: extreme imaging, distributed observers, a deep-space historical archive, and only then arbitrary historical retrieval. This paper develops the physical and engineering framework behind that strategy. Historical photon recovery (HPR) is evaluated through three gates: locate the relevant wavefront, reach an observation event that intersects it, and resolve the desired detail. At 500 nm, the Rayleigh criterion requires an ideal filled aperture of approximately 45 km to resolve Earth as a disk from 100 light-years, 577,000 km for a 1 km feature, and 577 million km for a 1 m feature. A simplified upper-bound photon model shows that a 10 m collector at that range would receive about 0.12 detected photons per second from the entire full-phase Earth and roughly one detected photon per 1 km surface element every 33 years before background and reconstruction losses. A sublight receiver launched from Earth cannot catch photons emitted before departure. Aestryn Archive therefore records future wavefronts prospectively; it does not recover pre-deployment history. Aestryn Retrieval evaluates conditional pathways such as wormholes, metric engineering, and teleportation-like systems against the criterion tau_access(D) < D/c. No such pathway is demonstrated. The company need not assume that breakthrough to exist: the known-physics program can produce testable systems, datasets, and intellectual property while the frontier program keeps arbitrary historical retrieval as a long-term research objective.

Central result
Aestryn can begin making future history independently observable without first solving teleportation. Pre-positioned observers can preserve delayed Earth-light under known physics. Arbitrary retrieval of light emitted before deployment remains a separate frontier objective and requires a pathway with tau_access(D) < D/c.

Contents

1. Introduction and scope

Every astronomical image is delayed. Sunlight reaches Earth in a little more than eight minutes; light from an object one hundred light-years away records that object roughly one hundred years earlier. NASA uses the same idea to explain why deep-space telescopes are lookback instruments [2]. Reverse the direction and the premise is straightforward: an observer one hundred light-years from Earth receives the portion of Earth's outward light field that left approximately one hundred years earlier.

The intuitive version of the idea is often stated too quickly. Being far away does not guarantee a useful view. The receiver must occupy the right spacetime event, face the right arrival direction, collect enough photons, separate Earth from the Sun and other backgrounds, and achieve the angular resolution needed for the requested feature. Clouds, nighttime, buildings, vegetation, scattering, and the orientation of reflective surfaces may prevent the event from encoding a direct line of sight at all. A telescope cannot recover information that never entered its aperture.

This paper asks a narrower question than time travel: under what physical and technological conditions could electromagnetic information corresponding to a previous terrestrial state be measured and reconstructed? The analysis is first order. It treats Earth as stationary when deriving scale laws, then identifies orbital motion, galactic motion, extinction, and relativistic corrections that a mission-grade model must add. It uses visible light near 500 nm for transparent comparisons, not because that wavelength is always optimal.

The contribution is not the observation that distant observers see the past. That is well known. The useful contribution is a single quantitative pipeline that maps a historical target - location, time, wavelength, desired resolution, and confidence - into observer geometry, effective baseline, collecting area, integration time, contrast control, and reconstruction uncertainty. The framework is designed to fail cleanly. If any gate is physically inaccessible or information-poor, the answer should be 'not recoverable under these assumptions,' not an invented image.

Aestryn's mission is to make history observable, but the company is not organized around a claim that teleportation will be invented. Aestryn Archive is the near-term engineering program: record Earth from increasingly distant, independent vantage points and reconstruct increasingly fine detail. Aestryn Retrieval is the long-term physics program: investigate whether any new spacetime-access technology could ever reach photons emitted before Aestryn existed. This separation lets the first program stand on demonstrated causality while the second remains an explicit, high-risk research question.

The optimistic case begins with a distinction between 'not available under today's demonstrated transport' and 'forbidden under every future theory.' This paper establishes the first statement for a sublight chase. It does not establish the second. That gap is the legitimate scientific space for Aestryn: identify which assumptions create the barrier, define the exact condition that would lift it, and build the optical and computational systems that would still be needed if access physics advances.

2. Definitions and research questions

Historical photon recovery (HPR) is defined here as the measurement and reconstruction of information corresponding to a previous physical state through electromagnetic radiation emitted, reflected, scattered, or otherwise modulated by that state. HPR does not mean that time reverses, that an observer enters the past, or that an event is recreated. It is closer to delayed remote sensing: the measurement occurs in the observer's present, while the detected field was shaped by an earlier source state.

A historical image is a stronger claim than a historical signal. A signal may establish that a source brightened, changed color, or occupied a coarse region. An image assigns spatially resolved radiance values. A scene reconstruction goes further by estimating geometry or objects from incomplete measurements. Those products must not be blended. Throughout this paper, measured data, algorithmic reconstruction, and model-based inference are treated as separate layers.

Information hierarchy
Existence -> Encoding -> Accessibility -> Recoverability. Radiation can exist without carrying the requested scene detail; encoded detail can propagate in a direction no observer can reach; accessible measurements can still be too incomplete or noisy for a unique reconstruction.

Aestryn research hypothesis
The current access barrier may be conditional rather than final. If nature permits a controllable shortcut, effective superluminal placement, or another causal pathway with tau_access(D) < D/c, historical-light interception becomes a concrete engineering problem instead of a geometric impossibility.

Research question	Operational test
RQ1 - Location	Where is the wavefront associated with an Earth event after a specified interval?
RQ2 - Access	Can a physically allowed observer trajectory intersect the required wavefront?
RQ3 - Resolution	What angular scale and effective aperture or baseline are required?
RQ4 - Signal	How many source photons enter the collecting area in the chosen band and exposure?
RQ5 - Separation	Can Earth be isolated from the Sun, zodiacal light, atmosphere, and detector noise?
RQ6 - Fidelity	Which scene properties are measured, reconstructed with priors, or merely inferred?
RQ7 - Maturity	Which elements are demonstrated, plausible engineering, speculative physics, or impossible under the stated model?

Table 1. Research questions translated into falsifiable tests.

3. Geometry of historical light

The speed of light in vacuum is exactly 299,792,458 m/s in the International System of Units [1]. For a stationary source-observer separation R in flat spacetime, the retarded time is

$$t_{emit} = t_{obs} - R/c$$

The observation records the source state at the emission time, not at the observation time.

An event at position r0 and time t0 contributes radiation to positions satisfying the light-cone condition

$$\|r - r_0\| = c(t - t_0)$$

At a fixed later time this is an expanding sphere; in spacetime it is the event's future light cone.

The phrase photon shell is a useful simplification, but it can mislead if taken literally. A short event produces a radially thin range of arrival times, while a long event produces a thick shell. Radiation is not uniform over the sphere: surface orientation, bidirectional reflectance, atmosphere, terrain, and illumination determine which directions carry signal. Photons from one person, building, or flash occupy a small and structured set of directions rather than a usable copy sent everywhere.

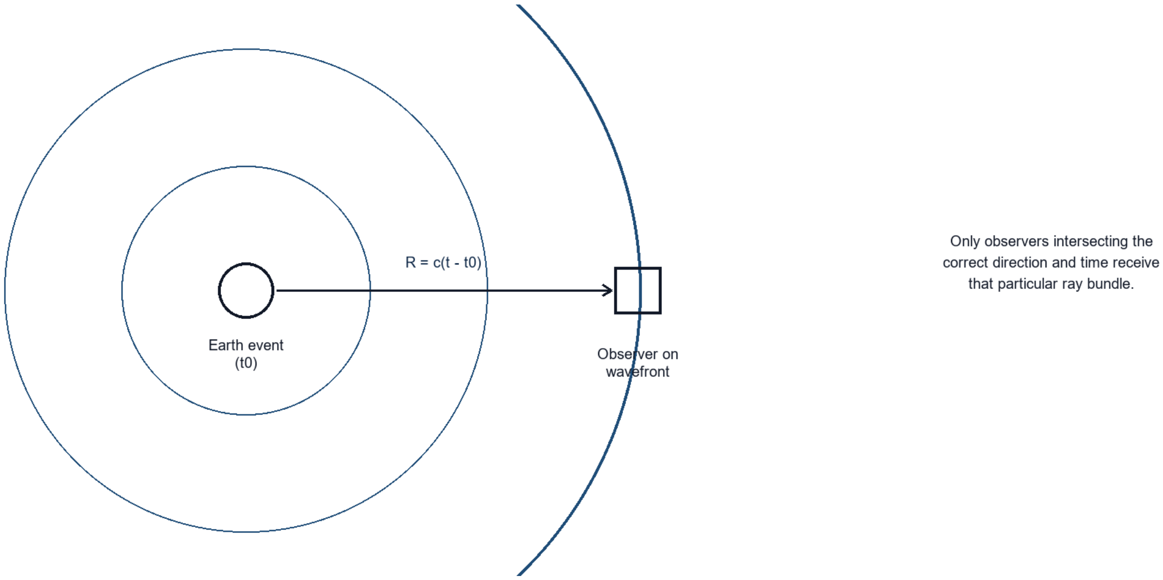

Figure 1. First-order photon-shell geometry. The shell identifies where a signal could be present; it does not guarantee brightness, visibility, or recoverable detail.

For lookback intervals above a few years, a precise locator must propagate Earth's barycentric position, the Solar System's motion, aberration, stellar proper motion, and the observer trajectory. These corrections matter to navigation, but they do not change the scale laws developed below. The leading-order radius remains R = c delta-t.

4. Aestryn program architecture

4.1 Archive and Retrieval

Aestryn Archive develops the systems needed to create a physically independent visual record of Earth under known physics. Its technical sequence is extreme imaging, distributed observers, and a progressively deeper historical archive. Aestryn Retrieval studies the additional access physics required to move from a prospective archive to arbitrary historical retrieval. The two programs share optics, timing, reconstruction, provenance, and mission analysis, but only Retrieval depends on an unknown physical breakthrough.

Aestryn progression
Extreme imaging -> distributed observers -> deep-space historical archive -> arbitrary historical retrieval. The first three stages can advance without assuming faster-than-light transport. The fourth cannot.

4.2 Locate-Reach-Resolve evaluation framework

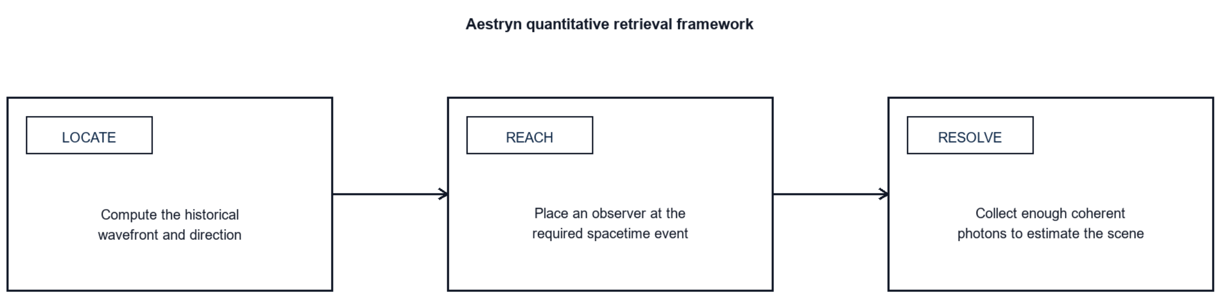

Figure 2. The three gates are sequential and non-substitutable. A large telescope cannot compensate for an inaccessible wavefront, and rapid transport cannot compensate for missing photons.

Locate converts a requested historical time into a candidate wavefront and arrival direction. Its input is not just a date. The target needs geodetic coordinates, duration, wavelength or band, illumination model, and desired spatial scale. A future spacetime search engine could return a region rather than a point because uncertainty in Earth ephemerides, scattering paths, and event duration expands the admissible observer volume.

Reach asks whether an observer or pre-positioned receiver can occupy that region at the required time. This gate is often skipped in popular descriptions, yet it is the hardest boundary for arbitrary recovery. A receiver already far away can record old Earth-light. A receiver launched after the desired photons leave cannot overtake them at sublight speed.

Resolve combines angular resolution, collecting area, contrast, exposure, and reconstruction. Effective baseline controls the finest spatial frequency that can be sampled. Collecting area controls photon rate. Array geometry controls Fourier-plane coverage. Phase and timing control determine whether the samples combine coherently. Reconstruction cannot manufacture unsampled spatial frequencies or unmeasured photons; it can only estimate within stated priors and uncertainties.

5. Angular resolution and diffraction

For a diffraction-limited circular aperture, the Rayleigh criterion gives an angular resolution near theta = 1.22 lambda/D. A feature of physical size s at distance R subtends theta approximately s/R for small angles. Combining the relations yields

D_filled approximately 1.22 lambda R / s = 1.22 lambda c delta-t / s
D_filled is the diameter of an ideal circular filled aperture under the Rayleigh criterion.

For an interferometer, the corresponding scale is B_interferometer approximately lambda R/s. The exact numerical factor depends on array geometry, projected baseline orientation, visibility definition, Fourier-plane coverage, and the reconstruction criterion. The table below uses the circular-aperture Rayleigh diameter as a consistent reference; an interferometric baseline should be interpreted as an order-of-magnitude requirement that can differ by an order-unity factor.

The linear scaling is severe. Doubling the lookback interval doubles the required aperture. Improving from kilometer detail to meter detail multiplies the requirement by one thousand. Shorter wavelengths reduce the required baseline, but ultraviolet operation introduces tighter surface tolerances, lower throughput, detector challenges, and interstellar extinction. No wavelength choice removes the geometry.

Lookback	Earth disk	1,000 km	1 km	1 m
1	0.453 km	6 km	5,771 km	5.77 million km
10	5 km	58 km	57,710 km	57.71 million km
100	45 km	577 km	577,105 km	3.86 AU
1,000	453 km	5,771 km	5.77 million km	38.58 AU

Table 2. Ideal circular-aperture Rayleigh diameter at 500 nm.

Source: author's calculation from the Rayleigh criterion. Interferometric baselines have the same scaling but architecture-dependent order-unity coefficients. Values exclude signal-to-noise, contrast, phase stability, and sampling losses.

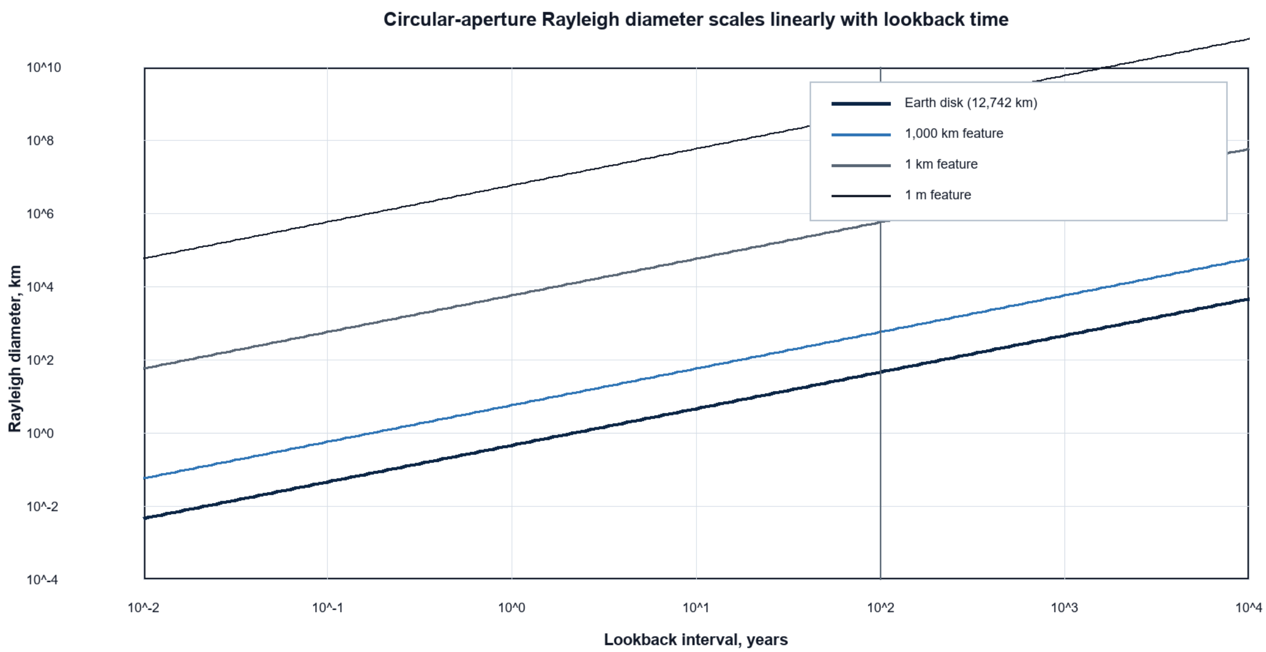

Figure 3. Required circular-aperture Rayleigh diameter versus lookback interval. An interferometer follows the same scaling with an architecture-dependent coefficient. The plot describes resolution, not collecting area or feasibility.

At one hundred light-years, Earth's 12,742 km diameter subtends about 1.35 x 10^-11 radians. The corresponding 45 km ideal aperture would only separate the planetary disk from a point. One-kilometer detail requires roughly 577,000 km - about 1.5 times the mean Earth-Moon distance. One-meter detail requires about 577 million km, or 3.86 AU. A real array would also need dense baseline coverage, nanometer-scale optical-path knowledge, sufficient collecting area, and long-term formation control.

6. Photon budget and temporal resolution

Resolution is not the same as detectability. A sparse array can have a very long baseline and still collect almost no light. A transparent first-order photon model is useful because it exposes the scale of the problem. Treat Earth as a Lambertian sphere at full phase with geometric albedo Ag = 0.30. Its planet-star flux ratio is approximated by Ag(Rp/a)^2, where Rp is Earth's radius and a is 1 AU. Represent a nominal 100 nm band from 500 to 600 nm, centered at 550 nm, with an assumed bolometric fraction f_band = 0.15 and end-to-end throughput of 20%. The band fraction is an explicit illustrative input, not a claimed integration of a specific solar spectral model.

N_dot = [L_sun/(4 pi R^2)] [Ag (Rp/a)^2] f_band A_collect eta / (hc/lambda)

This estimates detected photons from the unresolved full-phase Earth before background subtraction.

Using L_sun = 3.828 x 10^26 W and R = 100 light-years, a 10 m diameter collector yields about 0.12 detected photons per second from the entire disk. Dividing the illuminated disk into one-kilometer surface elements produces roughly 1.28 x 10^8 elements. The mean becomes about one photon per element every 33 years. This is not an exposure recommendation or a literal interferometric image-formation model. It is an information-density scale estimate showing how rapidly the available photon budget is diluted as requested spatial resolution increases. Real observations would be worse because the signal is not uniformly distributed, the planet is rarely full phase, clouds and atmosphere redistribute light, and the Sun and backgrounds contribute noise.

Collector diameter	Full-disk detected rate	Time per photon: 1,000 km element	Time per photon: 1 km element
10 m	0.12 s^-1	18 min	33 years
100 m	12 s^-1	11 s	122 days
1 km diameter filled aperture	1,208 s^-1	0.11 s	29 hours

Table 3. Simplified illustrative photon rates at 100 light-years.

Assumptions: full phase, Ag = 0.30, nominal 500-600 nm band represented by f_band = 0.15, 20% throughput, no background or losses beyond geometric dilution. Values scale with collecting area, not interferometric baseline.

Temporal resolution creates a second trade. A one-hour exposure averages rotation, cloud motion, lighting changes, and the event itself over that hour. Shorter exposures preserve time structure but collect fewer photons. If a requested scene lasts one second, no algorithm can replace the missing factor of 3,600 in photon count with a one-hour integration without changing what the image means. The output might estimate a static scene consistent with the data, but it would not be a one-second historical photograph.

7. Contrast, atmosphere, and occlusion

An Earth analogue in reflected light is approximately 10^10 times fainter than a Sun-like host at favorable visible wavelengths [4]. The maximum projected Earth-Sun separation from one hundred light-years is about 0.033 arcseconds and occurs near quadrature, when the reflected-light phase function is below its full-phase value. At full phase, used as the brightness ceiling in Table 3, Earth is nearly aligned with the Sun and direct separation is hardest. The photon estimate and the maximum-separation contrast estimate therefore describe different favorable limits, not one simultaneously achievable geometry. NASA's exoplanet program treats high dynamic range and angular resolution as coupled requirements, using coronagraphs, starshades, deformable mirrors, and wavefront control [4]. HPR inherits that difficulty before it begins resolving Earth's surface.

The atmosphere is part of the forward model, not a removable nuisance. Clouds may erase a direct surface view, haze and aerosols scatter spatial information, and absorption changes with wavelength. Nighttime scenes depend on artificial illumination and geometry. Even in daylight, a vertical wall and a horizontal roof send different reflected fields toward a distant observer. A historical event under cloud cover may have no direct visible-light path to the chosen direction.

Occlusion is absolute when no alternate path carries the information. If a person is inside a building, visible photons from that person do not escape through the roof. Thermal infrared or radio leakage may encode other properties, but the required detector, background model, and resolution scale change with wavelength. The correct scientific output is therefore conditional: recoverable surface radiance in a band and direction, not omniscient access to every event.

8. Interferometric architectures

Optical interferometry replaces one filled mirror with multiple collectors whose signals sample spatial frequencies. The Very Large Telescope Interferometer combines 8.2 m or 1.8 m telescopes across baselines up to roughly 140 m and must control optical paths with extreme precision [6]. NASA's Spectrally Resolved Synthetic Aperture Imaging Interferometer study explored digital correlation, frequency combs, single-photon detectors, and very large baselines for direct exoplanet imaging; sensitivity, not nominal baseline, emerged as a central limitation [5].

For HPR, a sparse array must satisfy at least four independent requirements: maximum baseline for angular resolution; total collecting area for photon rate; baseline diversity for Fourier-plane coverage; and timing, frequency, and position knowledge for coherent combination. A single pair of widely separated telescopes samples only a narrow set of spatial frequencies. A recognizable image requires many baselines, target rotation, array reconfiguration, or strong priors.

Quantum-assisted interferometry is a serious research topic but not a shortcut around causality or photon scarcity. Gottesman, Jennewein, and Croke proposed using quantum repeaters to extend optical interferometric baselines by avoiding the need to transmit fragile astronomical photons directly between sites [8]. The approach depends on high-quality entanglement distribution, quantum memories, and low-error operations that are not available at the scales considered here. It may improve how separated measurements are combined; it does not create photons that never reached the collectors.

Architecture	What it can improve	What it does not solve	Assessment
Filled aperture	Simple point-spread function; high collecting area	Deployment beyond tens of meters	Mature at telescope scale, impossible at HPR scale
Direct optical interferometer	Angular resolution with distributed collectors	Beam transport, phase stability, sparse coverage	Engineering frontier
Heterodyne/digital correlation	Longer baselines and post-detection combination	Quantum noise and sensitivity	Promising research path
Quantum-assisted array	Potentially relaxes inter-site photon transmission	Large entangled networks and memories	Early theoretical/experimental research
Solar gravitational lens	Natural gain and extreme angular resolution	Alignment beyond 548 AU; not Earth's own past from nearby	Early mission concept

Table 4. Candidate observing architectures and their actual role.

9. Observer accessibility

Proposition 1 - Sublight interception barrier

Suppose a receiver departs Earth at time zero, travels a distance D at constant speed $v < c$, and then looks back. It arrives after D/v. Light reaching it at that instant left Earth at

$$t_{emit} = D/v - D/c = D(1/v - 1/c) > 0$$

Any sublight receiver launched now sees Earth after departure, not before departure.

A receiver departing the source after an electromagnetic signal has been emitted cannot subsequently intercept that direct outgoing wavefront along a future-directed sublight trajectory. This is the decisive access boundary. A fast spacecraft can reduce how long after departure it sees Earth, but it cannot catch an older outward-moving wavefront. At $v = 0.9c$, the receiver still sees emission produced after launch. At v approaching c, t_{emit} approaches zero from above. No finite sublight speed makes t_{emit} negative.

Three paths remain logically distinct. First, an observer already positioned far away can record delayed Earth-light as it arrives. Second, probes deployed now can create a future distributed archive, useful to later observers but unable to retrieve pre-deployment history. Third, a genuinely superluminal transport mechanism or spacetime shortcut would change the geometry. No demonstrated technology provides the third path. Quantum teleportation transfers a quantum state using shared entanglement plus classical communication [12]; it does not instantaneously move a telescope or send usable information faster than light.

Boundary, not verdict
Aestryn cannot launch an ordinary sublight telescope and catch old light. That closes one mission profile, not every logically possible access pathway. The research question is what physical discovery, if any, can change Reach without violating a complete causal model.

9.1 Aestryn Observatory Network

The practical Archive architecture is a network of Aestryn Observatories moving outward from Earth and observing continuously. When an event occurs at time t0, its light propagates outward. Aestryn-1 intercepts the signal after one delay; Aestryn-2 intercepts it later. The stations do not wait to be told which event matters. They collect calibrated measurements, timing, pointing, spectral metadata, uncertainty, and provenance so that future users can query the archive after the event.

Node	Role	Observation epoch	Returned product
Earth reference	Defines target coordinates, clocks, and calibration sources	t0	Ephemeris and reference data
Aestryn-1	First independent outward vantage point	t0 + D1/c	Calibrated delayed measurements
Aestryn-2	More distant observer and longer delay	t0 + D2/c	Independent later-arriving measurements
Archive index	Links measurements to place, time, band, and confidence	After downlink	Queryable record with explicit uncertainty

Table 5. Conceptual Aestryn Observatory Network data flow.

D1 and D2 are observer distances along usable viewing geometries. The table describes prospective capture, not recovery of events that predate deployment.

Example archive query
Location: 33.1507 deg N, 96.8236 deg W | Time: August 25, 2052, 14:31 UTC | Band: visible | Resolution: maximum available. The result would contain only measurements actually captured by the network, with resolution and uncertainty stated explicitly.

10. Aestryn Retrieval: frontier access physics

Aestryn Retrieval is the frontier research division, not the dependency on which Aestryn Archive rests. The sublight interception barrier is a result within a stated regime, not a proof that every logically imaginable access mechanism fails. Regime I uses established causal transport: local motion and usable communication do not exceed c, and no traversable shortcut is available. In that regime, a newly launched observer cannot retrieve direct light emitted before departure. Regime II is conditional. It asks what would follow if a future technology could place an observer or instrument at the required spacetime region faster than a light signal following the ordinary external path. This section converts that possibility into testable requirements without claiming that any speculative mechanism already exists.

10.1 The Aestryn access criterion

Let tau_access(D) be the elapsed Earth-frame time required to place a functioning observer or receiver at an external separation D. Direct historical interception of a pre-departure wavefront becomes geometrically possible only if

tau_access(D) < D/c

Equality does not overtake the wavefront; a longer access time cannot recover pre-departure direct light.

For an idealized effective transit speed v, tau_access = D/v and t_emit = D/v - D/c. The expression becomes negative only when v > c. The table below shows the consequence for D = 100 light-years. It is a conditional geometry calculation, not evidence that superluminal motion can be engineered. Any physically complete proposal must also address energy conditions, horizon formation, control, stability, chronology, and how the destination is selected.

Effective speed	Transit time	Earth emission time	Conditional lookback before departure
2c	50 years	-50 years	50 years
10c	10 years	-90 years	90 years
100c	1 year	-99 years	99 years
1,000c	0.1 year	-99.9 years	99.9 years

Table 6. Conditional access geometry for a destination 100 light-years away.

These rows assume an effective transit time D/v and do not establish that v > c is physically realizable.

10.2 Traversable wormholes and spacetime shortcuts

A traversable shortcut is the cleanest mechanism-level example of the access criterion. If two externally distant regions were connected by a much shorter internal path, a receiver could travel locally below c while achieving tau_access < D/c relative to the external geometry. A mouth placed beyond an old Earth wavefront could therefore change the Reach result without a telescope locally outrunning light. Classical traversable-wormhole analyses, however, are theoretical spacetime models. Morris, Thorne, and Yurtsever linked traversable wormholes and chronology questions to violations of ordinary energy conditions [17]. Gao, Jafferis, and Wall later derived a traversable effect in a specific anti-de Sitter holographic construction using a quantum coupling [18]. Neither result provides a demonstrated macroscopic portal, a method for creating or positioning mouths, or a stable route through our astrophysical spacetime.

Aestryn wormhole question
Can a physically admissible shortcut connect an observer to a region containing an earlier Earth wavefront while remaining stable, controllable, and causally consistent?

10.3 Metric engineering and effective superluminal displacement

Alcubierre exhibited a general-relativistic metric in which a compact region is carried by expansion behind it and contraction ahead, allowing externally superluminal displacement while the payload remains locally timelike [19]. The original construction requires exotic stress-energy. Later work has classified broader warp geometries and found positive-energy subluminal examples, while superluminal versions retain major physical difficulties and still require a propulsion and control account [20]. These papers establish mathematical questions, not propulsion technology. Aestryn should therefore ask which stress-energy tensor, energy scale, horizon structure, stability condition, and steering law a proposed metric requires before using its effective speed in Table 6.

10.4 Teleportation, quantum information, and emergent spacetime

Existing quantum teleportation transfers an unknown quantum state using shared entanglement and classical communication [12]. It does not transport a person or telescope, and it does not permit controllable faster-than-light communication. A hypothetical macroscopic state-transfer system would have to encode or instantiate a functioning instrument at the destination. Its name is irrelevant to Reach: if its total transfer and reconstruction time is at least D/c, it does not satisfy the access criterion; if it is shorter, the proposal must explain the causal channel that makes that possible.

Quantum-gravity research does motivate serious questions about the relationship among entanglement, geometry, and traversability. A 2022 quantum-processor experiment implemented teleportation dynamics inspired by a holographic traversable-wormhole model [21]. It did not create a tunnel in laboratory spacetime. A published technical comment disputed whether the learned small Hamiltonian reproduced the claimed gravitational dynamics beyond its training operators [22], and the original authors responded that the implemented protocol retained the relevant size-winding interpretation [23]. The responsible conclusion is narrow: quantum simulation may test models of emergent geometry, but it is not evidence of a buildable portal.

10.4.1 Proposed Aestryn Teleportation Relay

Within Aestryn Retrieval, one proposed architecture is worth analyzing without elevating it into the company thesis. An Aestryn Teleportation Relay (ATR) would pair a source node with a pre-positioned destination platform containing quantum memory, a configurable optical instrument, power, pointing control, error correction, and enough physical substrate to instantiate a requested sensor state. The source would transfer a verified instrument-control state to the destination, the remote platform would configure itself, intercept the target wavefront, and return calibrated measurements. This avoids the undefined idea of teleporting a complete spacecraft from nothing; most mass and hardware already exist at the destination.

Under standard quantum teleportation, the classical verification message still limits completion to c or below, so the baseline ATR is a prospective infrastructure concept rather than a retrospective-access solution. The frontier variant asks a sharper question: could a future emergent-spacetime or traversable quantum channel replace that classical leg and make total deployment time tau_ATR(D) < D/c? A serious proposal would have to demonstrate end-to-end state fidelity, latency scaling with distance, causal consistency, remote embodiment, error correction, and a functioning optical payload. Until then, ATR is a research architecture, not evidence that faster-than-light teleportation exists.

Teleportation opportunity
The proposed ATR separates what can be engineered now - destination hardware, quantum memories, state verification, autonomous optics, and error correction - from the single unknown that matters for retrospective access: whether any future channel can complete the transfer in less than D/c.

10.5 Prospective historical capture and engineered delay

Known physics already permits a different version of the vision. Pre-positioned telescopes at increasing light-travel distances could continuously record Earth as its wavefront arrives. Autonomous probes could extend that network over decades or centuries. Future users would query stored measurements rather than chase photons after the fact. This prospective historical capture cannot recover events from before receiver deployment, but it can make future terrestrial history independently observable.

Engineered reflectors, optical relays, or digital archives could add deliberate delay. A relay ten light-years away that returned an optical signal would create a nominal twenty-year round trip. A more realistic receiver would detect the field, store calibrated amplitude-related measurements, phase where measurable, spectrum, timing, and polarization, then send the data back conventionally. The original photon need not return once its information has been measured. Resolution, pointing, data volume, and energy requirements remain severe, but the causal principle is ordinary and testable.

10.6 Delayed channels, enabling optics, and unknown physics

Naturally delayed channels - scattering, reflection, gravitational lensing, and multipath propagation - can make older signals arrive later than the direct path. Section 12 evaluates why such channels usually preserve coarse photometric or spectral information better than detailed terrestrial imagery. Metamaterials, superoscillatory methods, phase-front control, and related optical techniques may improve Resolve, yet no demonstrated version bypasses relativistic causality or supplies tau_access < D/c. The framework remains mechanism-agnostic: a future theory may be tested by its access time, causal structure, energy requirements, and destination control rather than by whether it uses the words warp, wormhole, or teleportation.

Two-breakthrough rule
Solving Reach does not solve Resolve. Even instantaneous placement 100 light-years away leaves the approximately 577,000 km scale for one-kilometer resolution, collecting-area demands, stellar contrast, clouds, viewing geometry, and reconstruction uncertainty.

10.7 Why the search remains open

The calculations in this paper rule out a sublight chase; they do not supply a universal no-go theorem covering every spacetime topology, quantum-gravitational effect, engineered-delay architecture, or future method of placing infrastructure. Unknown does not mean likely, and mathematical possibility does not mean buildability. It does mean the honest conclusion is 'unsolved,' not 'proven impossible.' Aestryn can make that distinction scientifically useful by publishing the assumptions behind each barrier and the evidence required to revise them.

Research layer	Breakthrough condition	What it unlocks	Status
Prospective archives	Pre-positioned receivers record outgoing Earth-light	Guaranteed delayed records of future events	Allowed by known physics; deployable in stages
Access physics	A controllable pathway achieves tau_access(D) < D/c	Retrospective interception of pre-departure light	Open theoretical frontier; no demonstration
Extreme imaging	Baseline, collecting area, contrast, and calibration scale together	Useful spatial detail from a remote Earth signal	Active engineering research
Historical observation	Access and imaging succeed in the same experiment	Defensible observation of an earlier terrestrial state	Ultimate Aestryn objective

Table 7. Aestryn's discovery ladder from known physics to the long-term objective.

Reason for hope
The ultimate result requires more than one breakthrough, but each layer has a clear success condition. Aestryn does not need to pretend the destination is close in order to begin moving toward it.

11. Information recovery and inference

A detector records counts, times, energies, polarizations, or correlations. An image is estimated from those measurements through a forward model. Shannon's communication theory formalized the role of noise and channel capacity [10]; HPR is an extreme inverse problem in which the channel includes propagation, atmospheric scattering, occlusion, telescope response, detector statistics, and sampling geometry.

y = H(x; Theta) + n
x is the historical terrestrial radiance field; H is the physical measurement operator; Theta contains geometry, atmosphere, reflectance, wavelength, optics, and array configuration; y is the detector data; n is noise.

x_hat = arg min_x [L(y, H(x; Theta)) + alpha R(x)]
L measures data mismatch, R expresses explicit regularization or prior information, and alpha controls the trade between them.

Identifiability is the boundary between reconstruction and invention. If two materially different scenes x1 and x2 satisfy H(x1; Theta) approximately H(x2; Theta) within the measurement uncertainty, the data do not recover the distinction between them. A reconstruction may still choose one solution through priors, but that choice must be labeled as inference rather than measurement.

Low-photon computational imaging can produce useful estimates. Kirmani and colleagues demonstrated three-dimensional imaging from the first detected photon at each pixel by exploiting spatial correlations and a controlled illumination model [9]. That result is relevant to algorithms and detectors, but it should not be misread.

Their method relies on active illumination, known timing, and strong scene priors. Passive historical observation at interstellar range has a different forward model and much weaker control.

Exoplanet mapping provides a closer analogy. Kawahara and Fujii showed that global surface distributions can be estimated from time-varying reflected-light curves under explicit assumptions about clouds, orbit, rotation, surface spectra, and static geography [11]. Such maps are coarse and model-dependent, yet scientifically meaningful. The lesson is constructive: an unresolved or sparsely resolved signal may support continental-scale albedo inference long before it supports literal historical photographs.

11.1 Information capacity and measurable modes

Photon counts per nominal surface element are useful for scale, but the deeper limit is the number of independent optical modes the instrument can measure. Finite collecting area, bandwidth, exposure time, angular field, baseline coverage, and detector response bound the available spatial, temporal, spectral, and polarization degrees of freedom. A mature analysis should replace simple pixel division with mode counts, Fisher information, and Cramer-Rao bounds for stated scene parameters. That work belongs in the reproducible simulation program; it is not solved by the present first-order estimate.

Output label	Permitted statement	Required evidence
Measured	A detector recorded this signal in the stated band and interval.	Calibrated raw data, uncertainties, provenance
Reconstructed	An inverse method estimated this image from measured samples.	Forward model, priors, residuals, ablations, confidence
Inferred	A model favors this class or property, not a unique image.	Competing models, posterior or error bounds
Simulated	This is the expected output under stated assumptions.	Synthetic ground truth and full parameter disclosure

Table 8. Evidence labels for preventing reconstructed detail from being presented as measurement.

Generative models are especially dangerous in this setting because realistic texture can hide missing information. A valid reconstruction pipeline should report the measurement-consistent component separately from prior-driven detail, test on withheld synthetic scenes, vary priors, and show residuals. If different plausible priors produce different faces, buildings, or vehicles while fitting the data equally well, those details are not recovered history.

12. Alternative optical pathways

Scattering can delay light and redirect it toward a later observer. Astronomers use light echoes from dust to study historical stellar eruptions; spectra of nineteenth-century light echoes from Eta Carinae revealed unexpected properties of the event [13]. This proves that delayed optical information can survive an indirect path. It does not imply that a dust cloud preserves a diffraction-limited terrestrial image. Scattering mixes angles, wavelengths, polarization, and time, usually destroying high-spatial-frequency information.

Reflections from the Moon and other Solar System bodies also contain delayed Earthshine. The delay is seconds to hours, not centuries, and the reflecting surface scrambles fine detail. Such signals may still support aggregate historical photometry or method validation. A useful near-term experiment is to measure how much spatial and spectral information survives a known diffuse reflector, then compare the result with the inversion's confidence claims.

The solar gravitational lens (SGL) is a different architecture. General relativity predicts strong focusing along a line beginning beyond roughly 548 AU. NASA NIAC studies have examined multipixel imaging of an exoplanet using a meter-class telescope in that region [14]. The SGL could transform exoplanet imaging, but it is a lens for an external source on the opposite side of the Sun, not a universal magnifying glass that can be pointed backward at arbitrary escaping Earth photons. The observer must be placed far beyond the Sun on the precise line opposite the external target; Earth's own outgoing rays and the desired historical geometry do not automatically satisfy that configuration.

13. Quantitative case studies

Case A - Earth as a disk, one hundred years. A receiver already located one hundred light-years away in the right direction receives approximately one-hundred-year-old Earth-light. At 500 nm, a 45 km ideal effective aperture separates the disk. High-contrast suppression is still needed to isolate Earth from the Sun, and useful surface science requires far more than one resolution element. This case is physically allowed but depends on a pre-existing remote observer.

Case B - one-kilometer feature, one hundred years. The circular-aperture Rayleigh diameter becomes about 577,000 km; an interferometric baseline has the same scale with an architecture-dependent coefficient. A 10 m collector provides only an order of 10^-9 detected photons per second per one-kilometer element in the simplified model. Increasing baseline without increasing collecting area does not change that rate. A 1 km diameter filled aperture, with about 0.785 square kilometers of collecting area, would improve the mean to about one photon per element every 29 hours, still before background, phase, and temporal requirements. A sparse implementation would need to distribute equivalent collecting area across a baseline larger than the Earth-Moon distance and combine it with extraordinary stability.

Case C - one-meter feature, one hundred years. The circular-aperture Rayleigh diameter is 3.86 AU. Relative to one-kilometer elements, there are one million times more one-meter elements, so the mean photon interval per element grows by the same factor for fixed collecting area. A 1 km diameter filled aperture would average about one photon per one-meter element every 3,345 years under the simplified unresolved-Earth model. This corrects a factor-of-100 error in version 1.0. Person-scale historical video is therefore even less credible as an engineering target than the earlier estimate implied.

Case D - one-day lookback. The relevant wavefront is one light-day away, about 173 AU. Diffraction is much easier: one-kilometer detail at 500 nm requires a baseline near 15.8 km. Access is still the problem. A receiver launched after the event cannot reach the already departed shell at sublight speed. A pre-positioned deep-space receiver could record it, making this a plausible architecture for future delayed archives rather than retrospective recovery.

Case	Physical signal	Access	Resolution	Overall conclusion
100 y / Earth disk	Exists	Requires pre-positioned observer	45 km ideal aperture	Allowed in principle; no historical deployment
100 y / 1 km	Extremely weak per element	Same access barrier	577,000 km baseline	Far beyond current optical arrays
100 y / 1 m	Photon-starved beyond plausibility	Same access barrier	3.86 AU baseline	Not a credible product target
1 day / 1 km	Much brighter than 100 y case	Shell already 173 AU away	15.8 km baseline	Future archive only if pre-positioned

Table 9. Case-study summary using the Locate-Reach-Resolve gates.

14. Feasibility and technology readiness

NASA technology readiness levels describe the maturity of technologies and systems, not the truth or maturity of established physical principles. NASA defines TRL 1 as basic principles observed, TRL 2 as a formulated concept, TRL 3 as analytical and experimental proof of concept, and TRL 9 as a flight-proven system [15]. HPR spans established physics, technology subsystems, mission concepts, and a nonexistent access mechanism, so one blended TRL number would be misleading.

Element	Status today	TRL treatment	Main gap
Finite-light-speed geometry	Established physics and astronomical observation	Not applicable	None at conceptual level
High-contrast exoplanet imaging	Laboratory and on-sky subsystem demonstrations	Assess by subsystem	10^-10 contrast, stability, throughput
Optical interferometric reconstruction	Operational arrays at approximately 100 m scale	Assess by subsystem	Orders-of-magnitude baseline and metrology
Photon-starved inverse imaging	Laboratory and field demonstrations	Assess by subsystem	Passive, unknown-scene, extreme-background validation
SGL exoplanet mission	Detailed studies and simulations	Mission-subsystem assessment	Travel beyond 548 AU and image inversion
Arbitrary old-wavefront access	Conditional mechanisms only; none demonstrated	Pre-technology; no official TRL	Must satisfy tau_access < D/c and a complete causal model

Table 10. Status of enabling elements. NASA TRLs apply to technologies and systems, not to established physical principles or nonexistent mechanisms.

The hard truth for a startup is that literal retrospective imaging cannot honestly be sold as a near-term product. The stronger thesis is: Aestryn is developing technology to preserve and recover visual information across time by exploiting the finite propagation of light. Aestryn Archive can create value through photon-starved computational imaging, sparse-aperture interferometry, distributed telescope synchronization, long-distance Earth imaging, reconstruction with explicit uncertainty, and tamper-resistant observational archives. Each area can produce experiments, datasets, software, or intellectual property without a 173-AU mission. Aestryn Retrieval preserves the upside if access physics changes, but it is not the premise investors must accept today.

15. Falsifiable research program

15.1 Aestryn Archive

A first research cycle should spend money on evidence that can kill weak claims. It should not begin with a giant telescope concept or a 173-AU spacecraft. The most useful output is an independently reproducible model linking target parameters to observer geometry, baseline, collecting area, exposure, background, and uncertainty. Every assumption should be editable, and the software should return explicit failure reasons.

Phase	Duration	Deliverable	Pass criterion	Stop or redirect trigger
Model	0-3 months	Open access-time, photon, contrast, geometry, and mode-count simulator	Independent reproduction within stated tolerance	Unexplained disagreement or hidden priors
Bench	3-8 months	Sparse-aperture photon-starved testbed	Repeatable gain on a pre-registered moving-target benchmark	No improvement over standard baselines
Stress	8-10 months	Cloud, occlusion, phase-error, and background tests	Calibrated uncertainty tracks real error	Confident hallucination under model mismatch
Replicate	10-12 months	External laboratory or advisor replication	Independent result and released failure cases	Result depends on undisclosed setup knowledge

Table 11. Twelve-month Aestryn Archive falsification program.

Three laboratory experiments are sufficient for the first cycle. First, a delayed-light geometry demonstration should use a pulsed source, controlled path lengths, and timestamped detection to validate the retarded-time software. Second, a sparse-aperture testbed should reconstruct known targets while baseline coverage, photon count, and phase error are varied systematically. Third, a blind reconstruction challenge should separate the team that generates scenes from the team that processes measurements, preventing the algorithm from benefiting from informal knowledge of the answer.

15.2 Aestryn Retrieval

A parallel theory track should maintain a mechanism registry for candidate access physics. Each entry should state tau_access(D), local versus effective velocity, stress-energy assumptions, causal structure, stability, destination control, failure modes, and the optical payload delivered at arrival. This does not turn speculative metrics into hardware. It makes speculative claims comparable and gives Aestryn a disciplined way to update Reach if physics changes. A mechanism changes the long-term program only if its complete access time satisfies tau_access(D) < D/c.

Progress does not require immediate success at the final objective. A credible first victory is an access model that outside physicists cannot easily break. A second is a photon-starved imaging result that materially outperforms accepted baselines. A third is a prospective archive demonstration that records a controlled event through a delayed path and reconstructs only what the measurements support. Each step makes Aestryn more capable even if the deepest access hypothesis remains unresolved.

The capital requirement should follow the apparatus and external-review plan, not a round number. The preliminary $750,000 target is plausible for a small twelve-month program using commercial optics and expert contractors, but it is not validated here. A financing memo should itemize salaries, detector and optics quotes, metrology, external replication, compute, legal/IP, insurance, and contingency. The research paper should not pretend that a proposed budget is a scientific result.

16. Ethics and governance

Even coarse retrospective sensing raises privacy and surveillance questions. A system capable of reconstructing prior activity would affect people who never consented to observation and could be used by states, litigants, employers, or private actors. The more realistic near-term tools - high-resolution remote sensing and inverse reconstruction - already have dual-use implications. Governance cannot wait for the ultimate historical capability.

Minimum safeguards include publishing the boundary between measurement and inference, labeling simulated or reconstructed imagery, keeping raw-data provenance, logging model and parameter versions, red-teaming misuse cases, and obtaining independent scientific review before public claims escalate. High-risk demonstrations should use controlled targets rather than unsuspecting people. Legal review should cover privacy, export controls, remote-sensing rules, and research partnerships before deployment.

Claims discipline is also an ethical requirement. Investors and the public should not be told that Aestryn can already see the past. The accurate description is that Aestryn studies information carried by outgoing light, develops enabling systems for extreme-distance computational imaging, and investigates the physical conditions under which retrospective access could become possible. The ultimate access problem remains unsolved, but it is an explicit research target rather than a discarded ambition.

17. Limitations and conclusion

The calculations in this paper are scale estimates, not a mission design. They assume flat spacetime, stationary first-order geometry, a representative wavelength and nominal band, simplified Earth reflectance, a full-phase brightness ceiling, and simplified detector performance. They omit interstellar extinction, exozodiacal and zodiacal backgrounds, detailed solar suppression leakage, polarization, atmospheric radiative transfer, complete array synthesis, relativistic navigation, data rates, spacecraft reliability, and cost. Each omission makes the results less complete; most make practical recovery harder.

Several results are nonetheless robust. Historical electromagnetic information propagates outward and can be observed at delayed times. A sublight receiver launched from Earth cannot catch radiation emitted before launch.

Diffraction imposes a baseline proportional to lookback interval and inversely proportional to desired spatial scale. Collecting area and baseline are different resources. Fine spatial and temporal detail divides an already weak signal into still fewer photons. Occlusion and scattering can remove or scramble information before it ever leaves Earth.

The scientific opportunity is therefore not a hidden loophole in time. It is a demanding intersection of causal geometry, astrometry, optical interferometry, high-contrast imaging, photon-counting detection, quantum information, and inverse problems. The reason to pursue it is precisely that the decisive barrier is conditional: this paper proves failure for a sublight chase, not failure for every future access mechanism. Aestryn can contribute now by building the technology for a physically independent visual archive, while Retrieval compares hypothetical mechanisms under one criterion. It will lose credibility only if it confuses an open frontier with a solved technology.

Conclusion
Aestryn is building the technology to create a physically independent visual archive of Earth, with arbitrary historical retrieval as the ultimate research objective. Archive advances under known physics. Retrieval remains unsolved and extraordinarily difficult, but it has a precise success condition: a complete pathway with $\tau_{access}(D) < D/c$ that also preserves enough signal to Resolve.

Appendix A. Constants and reproducibility notes

Quantity	Value used	Role
Speed of light, c	299,792,458 m/s (exact)	Wavefront radius and retarded time
Year	365.25 days	Light-year conversion
Visible wavelength	500 nm	Diffraction comparison
Photon-model wavelength	550 nm	Photon energy
Earth radius	6,371 km	Flux ratio and surface elements
Earth-Sun distance	149,597,870.7 km	Reflected-light ratio
Solar luminosity	3.828 x 10^{26} W	Illustrative photon budget
Geometric albedo	0.30	Illustrative full-phase model
Nominal photon band	500-600 nm	Explicit model definition
Band fraction / throughput	0.15 / 0.20	Simplified illustrative inputs

Table A1. Constants and assumptions used in the numerical examples.

Reproduction recipe. For a lookback delta-t and target size s, compute R = c delta-t and the circular-aperture Rayleigh diameter D_{filled} = 1.22 lambda R/s. For an interferometer use B approximately lambda R/s as the architecture-independent scale, then apply the coefficient appropriate to its array and reconstruction criterion. For the photon example, compute the stellar irradiance $L_{sun}/(4 \pi R^2)$, multiply by the full-phase planet-star ratio $A_g(R_p/a)^2$, the assumed band fraction, collecting area, and throughput, then divide by photon energy hc/lambda. The per-element rate divides the disk rate by $\pi R_p^2/s^2$. For a 1 km diameter filled aperture this gives about 29 hours per 1 km element and 3,345 years per 1 m element. The per-element division is an information-density heuristic, not an interferometric image-formation model. These equations intentionally expose their assumptions so that a reviewer can replace them.

Access-pathway comparison. For any proposed route to a destination at distance D, compute the elapsed Earth-frame access time $\tau_{access}(D)$, including acceleration, transit, deployment, stabilization, and optical acquisition. A pathway changes the Reach gate only if tau_access(D) < D/c. The conditional examples in Table 6 use the simplified relation tau_access = D/v and intentionally omit those overheads; they are geometry checks, not forecasts of realizable propulsion.

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