

PROXIMA-CENTRED

VISIBLE STARFIELD

Scientific methodology and reproducibility record

SCIENTIFIC CLASSIFICATION Catalogue-driven reconstruction of the visible stellar sky for a geometric observer at the Proxima Centauri system barycentre proxy. The catalogue transformation is the primary scientific result; raster products are secondary views. Accuracy is bounded by the accepted source data and explicit model limitations documented here.	
CONTROL	VALUE
Document	Proxima Starfield Scientific Methodology
Version	2.1 — scientific-scope and publication-status revision
Status	Controlled scientific and reproducibility record
Prepared	16 August 2026
Primary contract	CB04_PROXIMA_SCIENCE_1; downstream selection CB05_PROXIMA_RENDER_SCIENCE_1
Observer	Proxima Centauri stellar geometric state used as the operational system-barycentre proxy
Reception epoch	2028-07-12 00:00:00 UTC; J2028.5270384688256 TDB
Frozen visible set	1,491,263 distinct source rows with Proxima apparent V <= 11.5

Executive finding

The accepted workflow does not move pixels from an Earth sky map. It reconstructs one physical-emitter catalogue, propagates each usable stellar state through three-dimensional BCRS/ICRS space to a frozen reception epoch, shifts the origin to Proxima, solves the photon emission time, recalculates observer-relative direction and distance, and rescales apparent visual magnitude by inverse-square distance. A deterministic visibility predicate then yields exactly 1,491,263 distinct foreground sources.

CONCLUSION Within the frozen input catalogues, the stated epoch, the Proxima stellar-state proxy, the linear-motion or declared special-source models, and the documented fallbacks, the catalogue foreground is a scientifically reproducible Proxima-centred sky. It is not a photograph, a complete time-variable universe, or an independently transformed diffuse Milky Way model.

The controlled catalogue is the primary scientific product

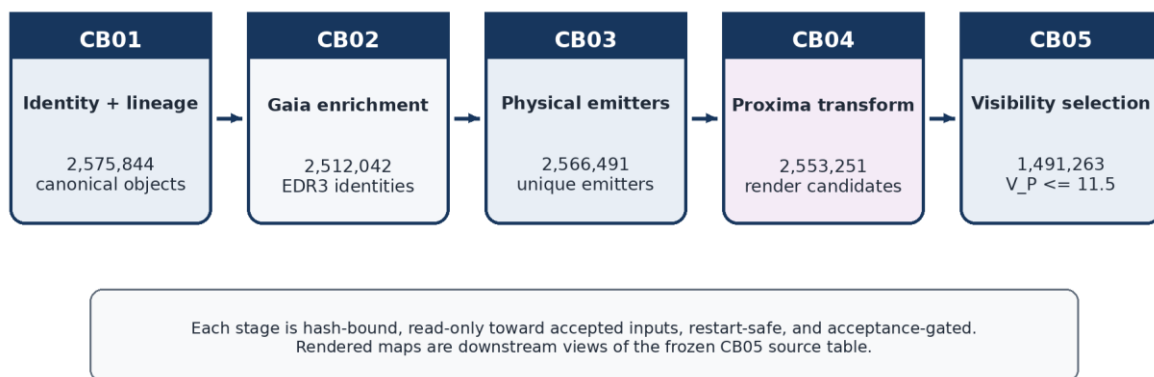


Figure 1 — Accepted build chain. Counts are records at each controlled stage, not image pixels.

Document purpose

This document is the durable explanation of how the accepted starfield was constructed. It intentionally avoids a catalogue of downloadable image products. The authoritative scientific object is the row-level transformed catalogue and its provenance; any ICRS, Galactic, preview, wall, navigation or constellation image is a consumer of that catalogue.

Where the implementation deliberately approximates physics, the approximation is named, counted or flagged. Where a quantity was not propagated—most importantly full covariance, source variability and new line-of-sight extinction—the document does not imply that it was.

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NOTATION Subscript E denotes the accepted Earth/catalogue-side value, P denotes the Proxima observer, t_R is reception time, $t_e = t_R - \Delta$ is photon emission time, and bold symbols are BCRS Cartesian vectors. Distances are parsecs unless stated otherwise.

1. Scope and scientific claim boundary

1.1 What is scientifically reconstructed

The reconstructed foreground contains catalogue-resolved stellar emitters. For each accepted emitter the database preserves identity, source lineage, input astrometry and photometry, the transformation route, output ICRS-aligned direction from Proxima, observer-relative distance when defined, apparent visual magnitude, uncertainty indicators and quality flags.

- Identity is resolved before geometry; multiple catalogue rows are not assumed to be multiple stars.
- Astrometry is propagated as a Cartesian state where a usable distance exists, so proper motion, radial motion, perspective and the change of observer origin act together.
- The apparent direction is evaluated at photon emission, not merely at the star's simultaneous target-epoch position.
- Apparent visual magnitude is changed only by the new geometric distance ratio; inherited passband calibration and extinction remain fixed.
- Every exception is an explicit route, not an undocumented substitution.

1.2 What is not claimed

- The output is not a camera exposure taken at Proxima and is not an absolute radiance survey.
- The NASA faint-star/diffuse Milky Way layer is fixed Earth-origin context. It was not re-ray-traced from Proxima and must not be used for Proxima astrometry.
- The catalogue is a single fixed-observer snapshot at the frozen reception epoch. It does not encode a vehicle trajectory, changing viewpoint or camera exposure.
- Except for Alpha Centauri A/B and the Sun, accepted sources use rectilinear motion; unresolved or nonlinear binaries may deviate from that model.
- No full source-by-source covariance was propagated. Quality fields and distance intervals are retained, but the output does not assert formal per-star error ellipses.
- Raster point-spread functions, halos and point sizes are display responses, not stellar angular diameters.

1.3 Primary versus secondary artefacts

The primary result is the immutable sequence of relational catalogues culminating in the Proxima-transformed emitter table and the visibility-selected source table. A rendered image is reproducible evidence that those records can be projected and visualized, but it is not the sole or highest-fidelity representation of the science.

CORRECT EVIDENTIARY ORDER Use database row values, transformation_method, quality_flags, provenance JSON, processing history and SHA-256 manifests to prove a source result. Use an image only to demonstrate the visual consequence of those records.

2. Frozen target, frames and units

2.1 Reception instant

The scientific contract freezes the observer reception instant as 2028-07-12 00:00:00 UTC. At contract freeze on 28 July 2026, TAI-UTC was assumed to remain 37 s. TT is therefore obtained by adding 37 s plus the fixed 32.184 s TAI-to-TT offset.

$$JD_TT = 2461964.5 + (37 + 32.184) / 86400 = 2461964.5008007409$$

ERFA eraDtdb evaluated at the geocentre with zero topocentric terms gives TDB-TT = -0.0002198577326498427 s for the frozen instant.

$$JD_TDB = 2461964.5008007386$$

$$J_TDB = 2000 + (JD_TDB - 2451545.0) / 365.25 = 2028.5270384688256$$

CHANGE RULE If a leap second is introduced before the target date, the UTC-to-TT mapping changes. The accepted result must not be silently recomputed; it requires a new scientific-contract identifier, runner version and build fingerprint.

2.2 Reference frame and observer

Vectors are expressed on BCRS/ICRS axes. The origin used for the sky directions is the target-epoch geometric stellar state of Proxima Centauri, operationally treated as the Proxima-system barycentre proxy. This is a stellar-trajectory proxy, not a numerical planetary-system barycentre from an n-body ephemeris.

OBSERVER-STATE FIELD	FROZEN VALUE
Gaia EDR3 source	5853498713190525696
HIP identity	70890
Accepted input distance	1.3019113540649414 pc
Accepted radial velocity	-21.942726135253906 km s ⁻¹
Target SSB distance	1.3015350044282568 pc
Position x,y,z	-97966.9981711, -74776.6876970, -238499.7915261 AU
Velocity vx,vy,vz	-0.00549932309505, 0.0127618364153, 0.0125179466297 AU day ⁻¹

2.3 Units and constants

Angles are stored in degrees at catalogue boundaries and converted to radians for vector operations. Proper motions are milliarcseconds per Julian year; ERFA position and velocity outputs are AU and AU per day. Distances are stored in parsecs. The implementation uses 365.25 days per Julian year, 206264.80624709636 AU per parsec and ERFA's speed of light constant in AU per day.

3. Source archive, identity and Gaia enrichment

3.1 Immutable source intake

CB01 read 79 frozen source payloads totalling 8,928,615,686 bytes. The intake manifest SHA-256 is db10f3c6bf5e1b34dc6fd3b23b9c0bcc0331cd239a8d1ad08f7a5fe92a67f8f0. All source byte counts and hashes passed before any catalogue construction.

SOURCE FAMILY	ACCEPTED MATERIAL	ROLE
Gaia cross-match tables	Tycho2tdscMerge best/neighbourhood; Hipparcos2 best/neighbourhood	Identity links; no new astrometry in CB01
Hipparcos New Reduction	CDS I/311, including 5/7/9-parameter and nonlinear annexes	System astrometry and full uncertainty terms
Original Hipparcos/Tycho	CDS I/239	Identity, correlations and double-star annex material
Tycho-2	CDS I/259	Main and supplements; position, motion and BT/VT photometry
Tycho Double Star Catalogue	CDS I/276	Component/system topology and photometry
XHIP	CDS V/137D	Selected Hipparcos astrometry, Johnson V, B-V and radial velocity
Yale Bright Star Catalogue	CDS V/50	Alias and completeness evidence; no blind positional merge

3.2 Identity before emission

CB01 constructed 2,575,844 canonical object records and an explicit relation graph. The identity backbone is catalogue identifiers and published cross-match routes, not a nearest-neighbour-only sky join. In particular, Yale BSC rows are linked by exact HD evidence where possible; position-only links are prohibited by an acceptance gate.

The build retained 24,588 Hipparcos component rows, 1,790,164 Hipparcos-2 uncertainty terms, 1,179,550 original-Hipparcos correlation terms and 97,797 unresolved/review cases. Unresolved topology was preserved as data rather than forced into silent emitter duplication.

WHY THIS MATTERS A geometrically excellent coordinate transform cannot repair a duplicated or wrongly merged source. Identity reconciliation is therefore part of the scientific method, not administrative preprocessing.

3.3 Gaia enrichment

CB02 queried the frozen set of 2,512,042 Gaia source identifiers through the ESA Gaia Archive asynchronous TAP interface. The exact ADQL joined `gaiadr3.gaia_source`, `gaiadr3.gaia_source` and `external.gaiadr3_distance` by `source_id`. Published missing quantities were retained as SQL NULL.

ENRICHMENT	COVERAGE	USE
EDR3 astrometry	2,512,042 rows; all at J2016.0	Position, parallax, proper motion, correlations, RUWE and quality fields
Bailer-Jones geometric distance	2,485,928 rows	Preferred production distance with posterior intervals
Bailer-Jones photogeometric distance	2,482,288 rows	Retained, but not the preferred CB04 geometric distance
Gaia DR3 radial velocity	2,311,053 rows	Used where present; uncertainty and quality retained

4. Consolidation into physical emitters

4.1 One emitter per accepted physical identity

CB03 reconciled catalogue representations into 2,566,491 physical emitters: 2,512,042 keyed by selected Gaia EDR3 source_id and 54,449 non-Gaia emitters collapsed by the CB01 render_group_key. Every one of the 2,575,844 CB01 object rows resolves to lineage or an explicit review state; lineage counts were corrected in CB03 v1.1.1 without changing astrometry, photometry or scientific policy.

4.2 Astrometric field precedence

For Gaia-keyed emitters, the accepted base-state precedence is deterministic:

1. Gaia EDR3 J2016.0 position and proper motion when both coordinates and both proper-motion components are present.
2. Tycho-2/TDSC mean J2000 position and motion when the Gaia motion tuple is incomplete.
3. XHIP selected solution for a clean, single-render-group Hipparcos system.
4. Gaia EDR3 position-only, then Tycho observed-position fallback, when no accepted motion tuple exists.

For non-Gaia groups, Tycho mean J2000 motion is preferred, followed by a clean XHIP solution and then a Tycho observed position. Rows remain flagged whenever the route is not an automatic Gaia 3D solution.

4.3 Distance, radial velocity and photometry precedence

$d_{in} = d_{BJ,geo}$ if finite; otherwise $1000 / \text{parallax}_{mas}$ pc if $\text{parallax} > 0$; otherwise infinity

The geometric Bailer-Jones median is used ahead of direct parallax inversion because the latter is unstable for noisy or non-positive parallax. Gaia DR3 radial velocity is preferred; XHIP radial velocity is accepted for the permitted Hipparcos fallback; otherwise radial velocity is set to zero only for propagation and the row is flagged ZERO_RADIAL_VELOCITY_FALLBACK.

Visual photometry is chosen independently from the astrometric identity. XHIP Johnson V is preferred for a clean single-group Hipparcos system; otherwise the frozen Tycho conversion is used, with Gaia EDR3 G explicitly labelled as an approximate visual fallback.

$$V = V_T - 0.090 (B_T - V_T) \quad \text{and} \quad B-V = 0.850 (B_T - V_T)$$

4.4 Earth-reference validation is a gate, not the Proxima transform

CB03 propagated an Earth-reference subset to ICRS/J2000 and reproduced the NASA Hipparcos/Tycho foreground conventions sufficiently to verify projection, orientation, catalogue crossover and approximate photometric scale. It did not relocate the sky to Proxima. The Proxima transform begins only in CB04 and consumes all 2,566,491 physical emitters without applying the Earth-side $V \leq 11.5$ cutoff.

5. Exact Proxima-centred astrometric transformation

5.1 Input astrometric tuple and basis

For an ordinary emitter, the input tuple is $(\alpha, \delta, \mu_\alpha^*, \mu_\delta, \text{parallax or accepted distance, radial velocity, base epoch})$. Gaia and CB03 store $\mu_\alpha^* = (d\alpha/dt) \cos \delta$. ERFA eraStarpv expects coordinate-angle proper motion, so production divides by $\cos \delta$ before the call.

$$\begin{aligned} \mu_\alpha &= \mu_\alpha^* / \cos(\delta) \quad ; \quad \mu_\delta = \mu_\delta \\ n &= [\cos(\delta) \cos(\alpha), \cos(\delta) \sin(\alpha), \sin(\delta)]^T \\ p &= [-\sin(\alpha), \cos(\alpha), 0]^T \quad ; \quad q_\delta = [-\sin(\delta) \cos(\alpha), -\sin(\delta) \sin(\alpha), \cos(\delta)]^T \end{aligned}$$

The familiar Euclidean interpretation is $r = d n$ and $v = v_r n + 4.740470463533349 d(\mu_\alpha^* p + \mu_\delta q_\delta)$, with d in pc, proper motion in arcsec yr⁻¹ and v in km s⁻¹. The production state is not reimplemented from this shorthand: it is generated by ERFA/SOFA eraStarpv, which enforces the catalogue conventions and perspective treatment.

5.2 Reconstruct the geometric catalogue-epoch state

eraStarpv returns a BCRS position/velocity state whose position is on the catalogue light-time convention. CB04 advances the returned position by its catalogue light time to reconstruct the geometric position at the catalogue epoch.

$$\tau_0 = |x_{\text{starpv}}| / c \quad ; \quad x_{\text{geo}}(t_0) = x_{\text{starpv}} + v \tau_0$$

Positions are AU, velocities AU day⁻¹ and c is ERFA's AU-per-day speed of light. The same procedure is used for the Proxima observer, which requires a complete accepted 6D tuple.

5.3 Propagate to the target reception epoch

For ordinary sources, constant BCRS velocity is assumed. With Julian epochs measured in years:

$$\begin{aligned} x_s(t_R) &= x_{\text{geo}}(t_0) + v_s [365.25 (J_R - J_0)] \\ x_P(t_R) &= x_{P,\text{geo}}(t_{P0}) + v_P [365.25 (J_R - J_{P0})] \end{aligned}$$

This is geometric propagation to a common reception time. It is distinct from the later light-time solution, which asks where the moving source was when the received photon left it.

Fixed-observer geometry and photon emission time

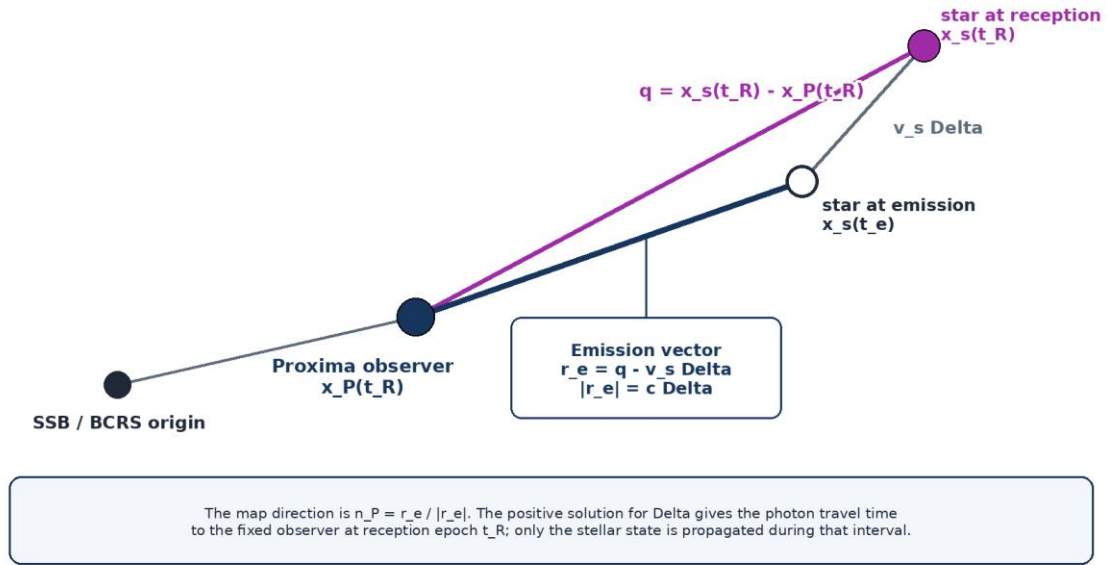


Figure 2 — Geometry used by the production finite-light-time solution.

5.4 Shift the origin and solve retarded light time

Let q be the simultaneous target-epoch vector from Proxima to the propagated star. During the photon flight time Δ , a linearly moving star was displaced backward by $v_s \Delta$. The geometric emission vector is therefore $q - v_s \Delta$ and must have length $c \Delta$.

$$q = x_s(t_R) - x_P(t_R)$$

$$|q - v_s \Delta| = c \Delta$$

Squaring gives a quadratic. CB04 uses the positive physical root:

$$\Delta = [-q \cdot v_s + \sqrt{(q \cdot v_s)^2 + (c^2 - |v_s|^2)|q|^2}] / (c^2 - |v_s|^2)$$

$$r_e = q - v_s \Delta \quad ; \quad d_P = |r_e| / \text{AU_per_pc} = c \Delta / \text{AU_per_pc}$$

$$t_e = t_R - \Delta$$

This retarded-time step accounts only for the source's catalogued motion during photon travel to the fixed Proxima observer.

The implementation rejects any case with $|v_s| \geq c$ and stores the residual $||r_e| - c \Delta|$. The production maximum residual was $3.814697265625 \times 10^{-6}$ AU, comfortably below the 1.0×10^{-4} AU acceptance limit.

5.5 Convert the emission vector to catalogue direction

$$n_P = r_e / |r_e|$$

$$\alpha_P = \text{atan2}(n_y, n_x) \bmod 2\pi \quad ; \quad \delta_P = \text{atan2}(n_z, \sqrt{n_x^2 + n_y^2})$$

The stored result is an ICRS-aligned astrometric coordinate direction as seen from the Proxima geometric origin. Right ascension is normalized to $[0, 360)$ degrees and declination to $[-90, 90]$ degrees.

5.6 Recalculate apparent visual magnitude

CB04 does not infer a new luminosity. It assumes the source luminosity, inherited passband calibration and inherited extinction are unchanged, and applies only inverse-square distance. If m_E is the accepted input apparent magnitude at input distance d_{in} and d_P is the retarded Proxima distance:

$$m_P = m_E + 5 \log_{10}(d_P / d_{in})$$

$$F_{rel} = 10^{(-0.4 m_P)}$$

No source-variability model, new line-of-sight extinction or passband reconstruction is applied. For a direction-only fallback with no distance, the magnitude is retained unchanged and flagged.

5.7 Declared transformation branches

Per-emitter transformation route

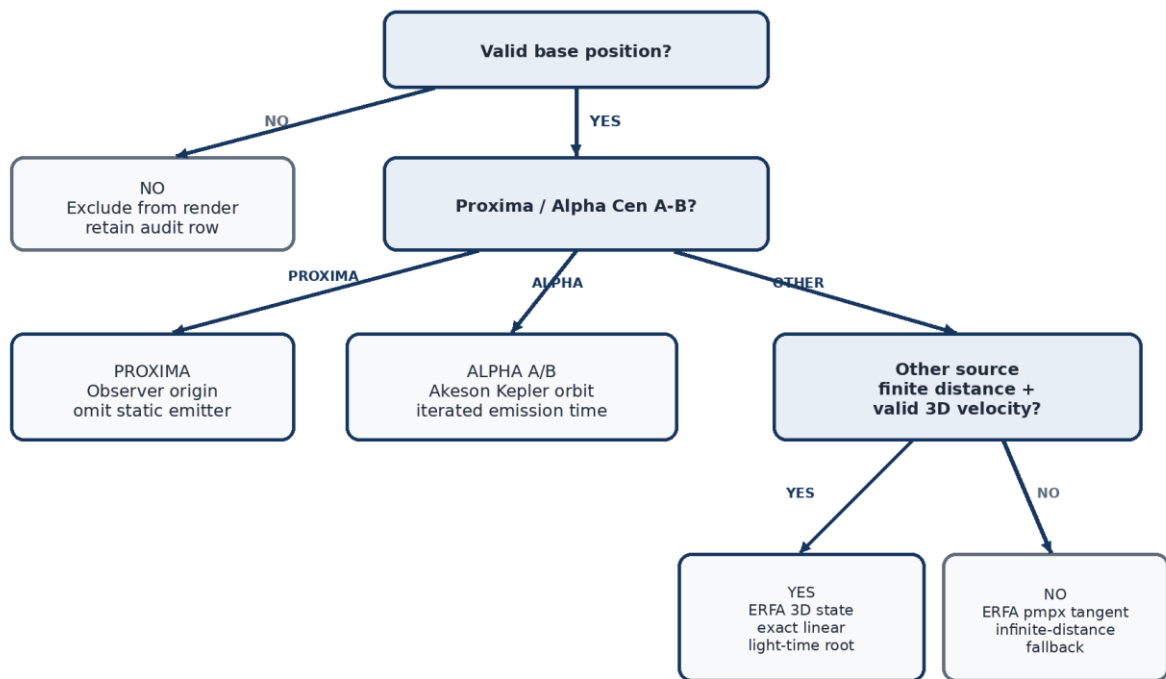


Figure 3 — Every emitter follows one named route; fallbacks remain queryable.

CASE	STORED METHOD	ACCEPTED COUNT	MEANING
Ordinary finite-distance	ERFA_STARPV_LINEAR_3D_EXACT_RETARDED_LIGHT_TIME	2,498,072 CB03 physical rows	3D state, constant velocity, exact quadratic light time
Infinite-distance tangent	ERFA_PMPX_TANGENT_INFINITY_DISTANCE_FALLBACK	55,162 CB03 physical rows	Proper-motion direction only; no observer parallax or magnitude rescale
Alpha Centauri A/B	AKESON_2021_ALPHA_AB_KEPLER_RETARDED_LIGHT_TIME	2 rows	Barycentric linear motion plus relative Kepler orbit at emission
Proxima identity	DYNAMIC_PROXIMA_SYSTEM_OMISSION	1 row	Defines origin; excluded from static sky
Invalid base position	NO_VALID_SOURCE_POSITION_EXCLUSION	13,254 rows	Retained in audit metadata, never a render candidate

CASE	STORED METHOD	ACCEPTED COUNT	MEANING
Yale/NASA completeness	STATIC_J2000_INFINITY_DISTANCE_COMPLETENESS_FALLBACK	18 rows	Direction and magnitude retained; no distance or motion
Sun	ERFA_EPV00_SOLAR_RETARDED_LIGHT_TIME	1 synthetic row	Solar barycentric ephemeris evaluated iteratively at emission

The counts in the table describe the complete CB04 transformed catalogue. Some flags overlap these branches: 240,152 physical rows used the explicit zero-radial-velocity fallback and 2,738 carried a nonlinear-motion warning.

5.8 Alpha Centauri A/B special model

Alpha Centauri is visually dominant from Proxima and its ~80-year binary orbit cannot be represented adequately by two independent rectilinear catalogue states. CB04 therefore replaces the generic route for HIP 71683 and HIP 71681 with the Akeson et al. (2021) barycentric astrometry and relative visual orbit.

$$M = 2\pi (t - T_0) / P \quad ; \quad E - e \sin(E) = M$$

$$x = \cos(E) - e \quad ; \quad y = \sqrt{1-e^2} \sin(E)$$

The orbital-plane coordinates are rotated by argument of periastron ω , node Ω and inclination i into local east, north and radial axes. If $f_A = M_A / (M_A + M_B) = 0.54266$ and r_{BA} is the B-minus-A relative vector, then $r_A = -(1-f_A)r_{BA}$ and $r_B = f_A r_{BA}$. The orbit is recomputed iteratively at photon emission until the light time changes by less than $1e-11$ day.

The accepted model produces an apparent A–B separation of 280.10831694287555 arcsec at the frozen reception epoch. Both components are retained as separate source identities.

5.9 Solar special source

The Sun is not a conventional stellar catalogue row. ERFA eraEpv00 provides Earth heliocentric and barycentric states; their difference gives the Sun's barycentric position. That position is evaluated iteratively at photon emission from the Proxima observer. With $M_V, \text{Sun} = 4.83$ and $B-V = 0.65$:

$$m_{V, \text{Sun}} = M_{V, \text{Sun}} + 5 \log_{10}(d_{P, \text{Sun}}) - 5$$

The accepted result is $d = 1.3015349813785537$ pc and $m_V = 0.40227922571268326$. The solar direction is within 0.005181554744642421 arcsec of the expected SSB antipode, providing an independent geometry check.

6. Population accounting: why the answer is 1,491,263

6.1 The count is a deterministic database result

The final count is not an estimate and is not the number of bright pixels. It is the number of distinct CB04 output rows that are valid render candidates and whose recalculated Proxima apparent visual magnitude is no fainter than 11.5. CB05 executes the following predicate over the immutable CB04 database:

```
SELECT COUNT(*)
FROM proxima_emitter
WHERE render_candidate = 1
      AND proxima_visual_mag <= 11.5;
-- accepted result: 1,491,263
```

LEDGER STAGE	ROWS	INTERPRETATION
CB01 canonical objects	2,575,844	Catalogue representations after identity/lineage construction
CB03 physical emitters	2,566,491	2,512,042 Gaia-keyed + 54,449 non-Gaia group emitters
CB04 total rows	2,566,510	Physical emitters + 18 BSC completeness rows + Sun
CB04 render candidates	2,553,251	Valid position and visual magnitude; Proxima origin omitted
Rejected by Proxima V>11.5	1,061,988	Candidates transformed successfully but fainter than the frozen limit
CB05 selected rows	1,491,263	58.406439% of CB04 candidates; all distinct source_output_row values

6.2 Why the Earth and Proxima populations differ

A star that is faint from Earth may be close to Proxima and become brighter; a familiar nearby Earth star may become much more distant or dimmer. Applying an Earth-side magnitude cut before relocation would therefore be scientifically wrong. CB04 transforms the entire 2,566,491-emitter physical catalogue first. Only after d_P and m_P exist does CB05 apply V_P≤11.5.

POPULATION INVARIANT The frozen set has 1,491,263 unique source rows, zero duplicate source keys, zero invalid selected coordinates, zero invalid selected magnitudes, minimum selected V=−6.796297594625196 and maximum selected V=11.5.

6.3 Row-level auditability

Every selected row retains source_output_row, source_key, optional Gaia/HIP/HR identifiers, Proxima coordinates, Proxima distance, magnitude, B−V, transformation_method, model_reference, uncertainty_status and quality_flags. The exact selected subset can therefore be re-queried without reproducing any raster.

The branch composition of the final subset is recovered with the GROUP BY query reproduced in Appendix C. The accepted top-level summary freezes the total, while the database preserves the finer-grained route evidence.

7. Coordinate frames and full-sky projection

Coordinate frames are rotations and projections, not new astrometry

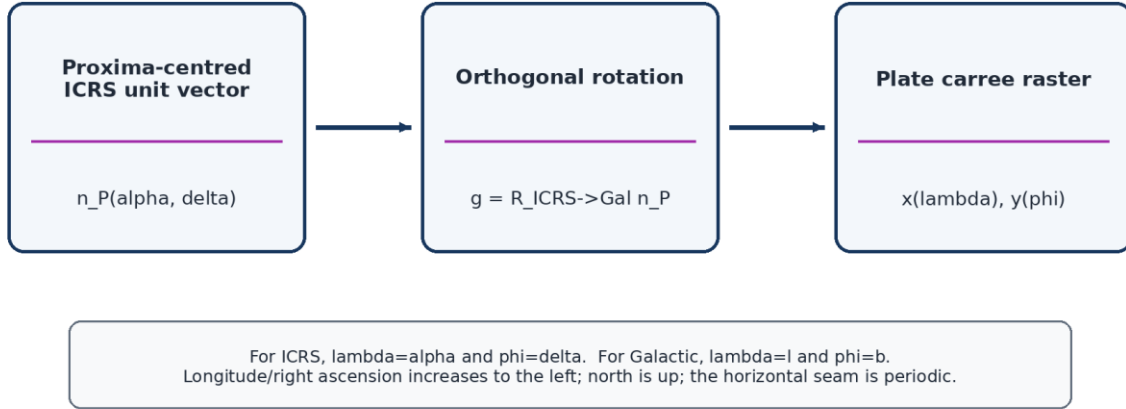


Figure 4 — A change of coordinate frame does not change the underlying observer-relative ray.

7.1 ICRS-aligned sky

CB04 stores the unit direction in ICRS axes. An ICRS publication map uses alpha and delta directly. The observer is not Earth, despite the familiar coordinate grid: only the axes are ICRS-aligned.

7.2 Galactic coordinates

The accepted Galactic view rotates the same Proxima-centred unit vector using the IAU/Hipparcos–Gaia J2000 orthonormal matrix R . No source is re-propagated and no magnitude is changed.

$$g = R n_P$$

$$R = \begin{bmatrix} -0.0548755604162154 & -0.8734370902348850 & -0.4838350155487132 \\ 0.4941094278755837 & -0.4448296299600112 & 0.7469822444972189 \\ -0.8676661490190047 & -0.1980763734312015 & 0.4559837761750669 \end{bmatrix}$$

$$l = \text{atan2}(g_y, g_x) \bmod 2\pi \quad ; \quad b = \text{asin}(g_z)$$

7.3 Plate carrée mapping

For image width W , height H , horizontal longitude λ and latitude ϕ , the stored convention centres zero longitude, makes longitude increase to the left and keeps north up:

$$x = W [(0.5 - \lambda / 2\pi) \bmod 1] \quad ; \quad y = H (0.5 - \phi / \pi)$$

Use $(\lambda, \phi) = (\alpha, \delta)$ for ICRS and (l, b) for Galactic. The horizontal seam is periodic. Plate carrée strongly stretches shapes near the poles; this is projection geometry, not a physical elongation in the sky.

7.4 Coordinate correctness tests

- All selected ICRS coordinates are finite and within the contractual ranges.

- ICRS→Galactic→ICRS round trips are acceptance-tested to below 1e−6 degree.
- Orientation alternatives—RA mirrored, RA=0 at an edge and declination flipped—were tested against the Earth-reference map and rejected by correlation margins.

8. Photometry, colour and rendering boundary

8.1 The scientific photometric quantity

The catalogue's defensible photometric quantity is relative apparent visual flux implied by m_P . It preserves source ordering and inverse-square changes, but it is not an absolute physical radiance calibration. The reference zero point cancels when relative flux is used.

$$F_1 / F_2 = 10^{[-0.4 (m_1 - m_2)]}$$

8.2 Display colour

Accepted B−V is converted to an approximate effective temperature with the Ballesteros relation, clipped to $-0.40 \leq B-V \leq 2.00$. Missing B−V uses the explicit neutral fallback 0.65; 918 of the 1,491,263 selected rows use it.

$$T = 4600 [1/(0.92(B-V)+1.7) + 1/(0.92(B-V)+0.62)] \text{ K}$$

Temperature is mapped to approximate blackbody sRGB and linearized; RGB is normalized to unit Rec.709 luminance before multiplication by relative flux. This is a stable visualization mapping, not spectrophotometry. Gaia BP−RP provenance is retained, but rows without accepted B−V are not silently treated as calibrated B−V.

8.3 Rasterization

The accepted master places sources bilinearly at subpixel plate-carrée coordinates and applies a separable Gaussian visualization PSF. At the 65,536x32,768 master, $\sigma_y=11.2$ pixels and the kernel radius is 34 pixels; $\sigma_x=\sigma_y/|\cos(\text{latitude row})|$ accounts for plate-carrée angular scale. Polar boundaries reflect with a 180-degree longitude shift, and longitude wraps periodically.

INTERPRETATION PSF width, halo and bright-source core are raster responses for readability. They must never be cited as angular size, diffraction, atmospheric seeing or a Proxima-based instrument response.

8.4 Fixed NASA context layer

The NASA Deep Star Maps 2020 milkyway_2020_64k layer supplies a high-quality faint-star/diffuse context. It remains an Earth-origin Gaia DR2 visualization. The transformed catalogue foreground may be combined with it for visual continuity, but the composite must be described as a controlled scientific visualization, not as a fully Proxima-transformed sky at all spatial scales.

9. Validation and acceptance evidence

9.1 Layered acceptance model

GATE LAYER	EVIDENCE	FAILURE PREVENTED
Input immutability	SHA-256, byte counts, exact schemas and frozen row counts	Prevents accidental source substitution
Database integrity	SQLite quick_check, foreign keys, unique keys	Prevents structural corruption and duplicate identities
Astrometric algorithm	Synthetic vectors, ERFA/SOFA routines, retarded residual	Tests equations independently of a sky image
Special sources	Proxima omission, Alpha A/B separation, solar antipode	Tests local geometry and exceptional models
Population	Exact candidate and selected counts	Proves that selection is deterministic
Projection	Round trips and orientation correlations	Proves axes, handedness and seams
Raster conservation	Flux and reduction error gates	Proves downstream maps preserve catalogue weighting

9.2 Accepted quantitative checks

METRIC	ACCEPTED VALUE	DECISION
CB04 output / render candidates	2,566,510 / 2,553,251	PASS
Duplicate CB04 source keys	0	PASS
Invalid render coordinates / magnitudes	0 / 0	PASS
Maximum light-time residual	3.814697265625e-6 AU; limit 1.0e-4 AU	PASS
Observer SSB distance	1.3015350044282568 pc	PASS plausible
Sun distance / V	1.3015349813785537 pc / 0.4022792257	PASS plausible
Sun antipode offset	0.0051815547 arcsec	PASS
Alpha A/B apparent separation	280.1083169429 arcsec	PASS
Selected distinct sources	1,491,263	PASS
Selected duplicates / invalid values	0 / 0	PASS
Master foreground flux relative error	1.4123803e-6	PASS
64K→16K radiance relative error	4.1936023e-7	PASS

9.3 Warnings are retained evidence

CB04 completed with five warnings, not failures: 13,254 invalid-position rows, 4 rows without visual magnitude, 55,162 tangent fallbacks, 240,152 zero-RV fallbacks and 2,738 nonlinear-motion warnings. These are visible in summary metrics and row flags. Their presence does not mean they were ignored; it bounds how each row may be interpreted.

The Earth-reference comparison produced coarse log-luminance correlation 0.6989588017 and an orientation margin 0.6774036817 against flipped/mirrored alternatives. This validates the inherited projection and approximate foreground scale; it is not a claim that the reconstructed catalogue is pixel-identical to NASA's different source compilation.

10. Uncertainty, limitations and correct use

10.1 Uncertainty policy

The catalogue preserves parallax errors, Bailer-Jones distance quantiles, Gaia RUWE, duplicated-source flag, astrometric excess noise, solution code, radial-velocity error and nonlinear-motion indicators. It does not propagate the full astrometric joint covariance to a formal Proxima-sky covariance.

Each source direction is therefore the deterministic result of accepted point estimates and its model route, not an uncertainty-free truth. Precision navigation or scientific inference requires quality filtering and dedicated covariance or Monte Carlo propagation from the source catalogue.

10.2 Model limitations

DOMAIN	BOUNDED LIMITATION
Observer	Proxima stellar trajectory proxy; unmodelled planetary/reflex displacement is small at intended image sampling but non-zero.
Motion	Constant space motion for ordinary sources; orbit model only for Alpha Cen A/B.
Distance fallback	No accepted distance -> tangent propagation, no observer parallax, magnitude unchanged.
Radial velocity	Missing value -> zero for propagation and explicit flag; perspective evolution can be biased.
Time scale	Catalogue TCB proper-motion time versus TDB/TT interval distinction neglected per SOFA starpv guidance; below accepted catalogue accuracy.
Photometry	No source variability, new extinction or passband reconstruction.
Snapshot geometry	Fixed geometric observer and one reception epoch; no vehicle trajectory or time-varying viewpoint.
Diffuse sky	NASA context remains Earth-origin and is not valid for Proxima astrometry.
Raster	Point-spread functions and tone mapping are visual, not physical source morphology.

10.3 Appropriate claims

- Appropriate: 'catalogue-derived apparent direction and relative visual brightness for a Proxima-centred geometric observer at J2028.5270385 under the documented model.'
- Appropriate: 'scientifically reproducible foreground, validated by immutable inputs, row-level provenance and acceptance gates.'
- Not appropriate: 'exact photograph from Proxima' or 'complete physical appearance of the Milky Way from Proxima.'
- Not appropriate: sub-arcsecond navigation claims without filtering and propagating source uncertainties.

11. Reproduction and change-control protocol

11.1 Rebuild sequence

STEP	RUNNER	REQUIRED OPERATION	FROZEN CHECKPOINT
1	CB01 v1.2.2	Verify 79-file manifest; rebuild identity/lineage database	2,575,844 canonical objects
2	CB02 v1.0.2	Query frozen Gaia EDR3/DR3/distance joins or reuse verified database	2,512,042 enriched source IDs
3	CB03 v1.1.1	Resolve physical emitters and pass Earth-reference validation	2,566,491 emitters
4	CB04 v1.0.0	Resolve target time/observer; transform all emitters; special sources; gates	2,566,510 rows; 2,553,251 candidates
5	CB05 v1.1.0	Apply Proxima $V \leq 11.5$ selection; preserve row identity; optional render	1,491,263 selected rows

11.2 Minimum audit procedure

1. Copy the source archive; never modify the accepted intake in place.
2. Verify every input manifest, byte count and SHA-256 before opening a build database.
3. Run each runner's self-test and preflight using its locked environment, then execute it without bypassing acceptance gates.
4. Confirm program, runner version, scientific contract, build fingerprint, input hashes and dependency versions in the summary/provenance files.
5. Confirm the population ledger and all mandatory PASS metrics in Sections 6 and 9.
6. Archive the database, schema, report, provenance, processing history, acceptance metrics and SHA-256 manifest together.
7. Treat any changed input, epoch, observer model, precedence rule, special-source model or magnitude limit as a new scientific version.

11.3 Reproducibility invariants

- No duplicate source_key in CB04 and no duplicate source_output_row in the selected table.
- Proxima's own identity is absent from the static selected population.
- Alpha Centauri A and B are present as two unique identities and use the orbit model.
- The Sun is one explicit synthetic source using the ephemeris model.
- Selected rows satisfy finite coordinate and magnitude ranges and the exact $V \leq 11.5$ predicate.
- Observer state, reception epoch and transformation-model identifiers remain exactly frozen unless a new contract intentionally changes them.

11.4 Change-impact rules

CHANGE	SCIENTIFIC IMPACT	REQUIRED VERSION BOUNDARY
New leap second / target epoch	Recompute target TT/TDB and every propagated state	New CB04 contract and all downstream fingerprints

CHANGE	SCIENTIFIC IMPACT	REQUIRED VERSION BOUNDARY
New Gaia or distance catalogue	Identity/astrometry/uncertainty may change	New CB02 onward
Changed emitter resolution	Physical population and lineage change	New CB03 onward
Changed Proxima state	Every observer-relative direction/distance changes	New CB04 onward
Changed V limit	Astrometry unchanged; selected population changes	New CB05 selection contract
Changed colour/PSF/tone	Catalogue astrometry unchanged; appearance changes	New rendering contract only
Changed NASA background	Foreground science unchanged; composite context changes	New visual-product provenance

Appendix A. Constants and special-source parameters

A.1 Core numeric constants

CONSTANT	VALUE	ROLE
Target UTC	2028-07-12T00:00:00Z	Frozen reception label
TAI-UTC	37 s	Assumed at 2026-07-28 contract freeze
JD(TT)	2461964.5008007409	Target dynamical time
JD(TDB)	2461964.5008007386	ERFA eraDtdb correction
Julian epoch TDB	2028.5270384688256	Propagation reception epoch
AU per pc	206264.80624709636	Distance conversion
Velocity conversion	4.740470463533349 km s ⁻¹	1 arcsec yr ⁻¹ at 1 pc
Physical distance ceiling	9,999,999 pc	ERFA 3D admissibility guard
Source-state velocity ceiling	100,000 km s ⁻¹	Above -> tangent fallback
Magnitude limit	V_P ≤ 11.5	Post-transform selection

A.2 Alpha Centauri A/B model

PARAMETER	FROZEN VALUE
Reference epoch	2019.5
Barycentre RA / Dec	219.85892215 deg / -60.83163195 deg
Barycentre proper motion	mu_alpha*=-3639.95; mu_delta=700.40 mas yr ⁻¹
Barycentre RV / parallax	-22.3796 km s ⁻¹ / 750.81 mas
Relative semimajor axis	17.4930 arcsec
Inclination / omega / node	79.2430 deg / 231.519 deg / 205.073 deg
Period / periastron epoch	79.762 yr / 1955.564
Eccentricity	0.51947
A mass fraction	0.54266

A.3 Solar model

PARAMETER	FROZEN VALUE
Barycentric position	ERFA eraEpv00: barycentric Earth minus heliocentric Earth
Emission solve	Iterative, tolerance 1e-11 day, maximum 32 iterations
Absolute visual magnitude	M_V=4.83
Colour	B-V=0.65

Appendix B. Field-precedence and fallback matrix

QUANTITY	PREFERRED	FALLBACK	AUDIT TREATMENT
Identity	Selected Gaia EDR3 source_id	CB01 render_group_key	Never positional-nearest-only
Base position/motion	Gaia EDR3 J2016 4-parameter tuple	Tycho mean -> clean XHIP -> position-only	Route stored in base_astrometry_source
Distance	Bailer-Jones EDR3 geometric median	Positive parallax inversion	Else infinite-distance tangent
Radial velocity	Gaia DR3	XHIP	Else zero for propagation and flag
Visual magnitude	Clean XHIP Johnson V	Tycho BT/VT -> Gaia G approximate	No value -> not a render candidate
B-V	XHIP B-V	Tycho BT/VT	Missing -> neutral display fallback only
Ordinary motion	ERFA starpv + constant velocity	ERFA pmpx tangent	Nonlinear flag retained
Alpha Cen A/B	Akeson 2021 orbit	None	Generic route is replaced
Sun	ERFA epv00 special source	None	Not a catalogue emitter
Proxima	Observer-state source	None	Omitted from static sky

B.1 Fallback interpretation

A fallback is not equivalent to a failed build. It is a controlled model with a narrower claim. A tangent source supports a propagated catalogue direction but not Proxima parallax or inverse-square magnitude relocation. A zero-RV source supports a 3D solution under $v_r=0$ but carries greater risk of perspective error. A nonlinear flag means the point estimate remains usable for visualization while an unmodelled orbital trajectory may dominate high-precision work.

Appendix C. Verification queries and pseudocode

C.1 Population checks

```
-- Complete transformed table
SELECT COUNT(*) FROM proxima_emitter; -- 2,566,510
SELECT COUNT(*) FROM proxima_emitter WHERE render_candidate=1; -- 2,553,251
-- Frozen visible set
SELECT COUNT(*) FROM proxima_emitter
WHERE render_candidate=1 AND proxima_visual_mag<=11.5; -- 1,491,263
-- Selected branch composition
SELECT transformation_method, COUNT(*) FROM proxima_emitter
WHERE render_candidate=1 AND proxima_visual_mag<=11.5
GROUP BY transformation_method ORDER BY COUNT(*) DESC;
-- Uniqueness
SELECT COUNT(*) - COUNT(DISTINCT source_key) FROM proxima_emitter; -- 0
```

C.2 Per-source reproduction pseudocode

```
for each CB03 physical emitter:
    choose base position, proper motion, distance and radial velocity by frozen precedence
    if emitter is Proxima: record origin omission
    elif emitter is Alpha Cen A or B: evaluate Akesson orbit at retarded emission time
    elif base position invalid: record exclusion
    elif finite admissible distance and a valid 3D velocity:
        pv = ERFA.starpv(alpha, delta, mu_alpha*/cos(delta), mu_delta, 1/d, rv)
        v_s = pv.velocity
        x_geo0 = pv.position + v_s * |pv.position|/c
        x_reception = x_geo0 + v_s * 365.25*(J_R - J_0)
        q = x_reception - x_Proxima(J_R)
        solve |q - v_s*Delta| = c*Delta using the positive root
        r_emit = q - v_s*Delta
        direction = normalize(r_emit); d_P = |r_emit|
        m_P = m_E + 5*log10(d_P/d_in)
    else:
        direction = ERFA.pmpx(alpha, delta, proper_motion, zero_parallax, zero_rv)
        m_P = m_E; record infinite-distance fallback
    write method, model reference, residual, uncertainty status and quality flags
```

C.3 Coordinate checks

```
n = [cos(delta)cos(alpha), cos(delta)sin(alpha), sin(delta)]
g = R_ICRS_TO_GALACTIC @ n
l = atan2(g_y, g_x) mod 2*pi
b = asin(g_z)
assert angular_distance(n, R.T @ g) < 1e-6 degree
```

Appendix D. Controlled versions, hashes and references

D.1 Accepted runners and databases

STAGE	VERSION	RUNNER SHA-256	ACCEPTED DATABASE SHA-256
CB01	1.2.2	runner 90a4342285ef35879534424a3a0d68519841a10f65a7 de2c1de6583a93672951	DB 7a580f8f67665dc55d9c750c84dd7a5b189ca4fb57838 9914e50f326db2ffac6
CB02	1.0.2	runner c3678759983ab915109a7544ce22b96a1cd85cc02366 4f9d02311b58bb7b0e85	DB 7dc897df090e6169e11ae1ab3edbe9b185366588212f9 a8ef14fe15f13cf3253
CB03	1.1.1	runner 5b1ee8c0bd83a1bd89e38622635a6f6bf07fb8760240 64136ac6088edfa875f4	DB dbf039aae226a0590f2b710d2721645cf18616eb49ea9 a419dde0a7d37335ef7
CB04	1.0.0	runner d06d9a1aaed279be14d29cd54b8adbe63e4ddc66f89 e2d77f2c71f530cc773bb	DB 3b9965b01ccc7bc4c158a0837f08b9456b1bec809bdf3 156d086c9d19733d89b
CB05	1.1.0	runner 52bef3cbc806d5ca93adcc62e504a9001f60b31d9a61 db6499d56a7b1fdd229d	accepted DB 65992b137aab60ee3af08b5fa52a93ee16caac9313506 52e78646a09dda5909e

Build fingerprints: CB03 133b475e5dfa407b; CB04 7715d6d2ab3b7110; CB05 4e5880ec96e141f7.

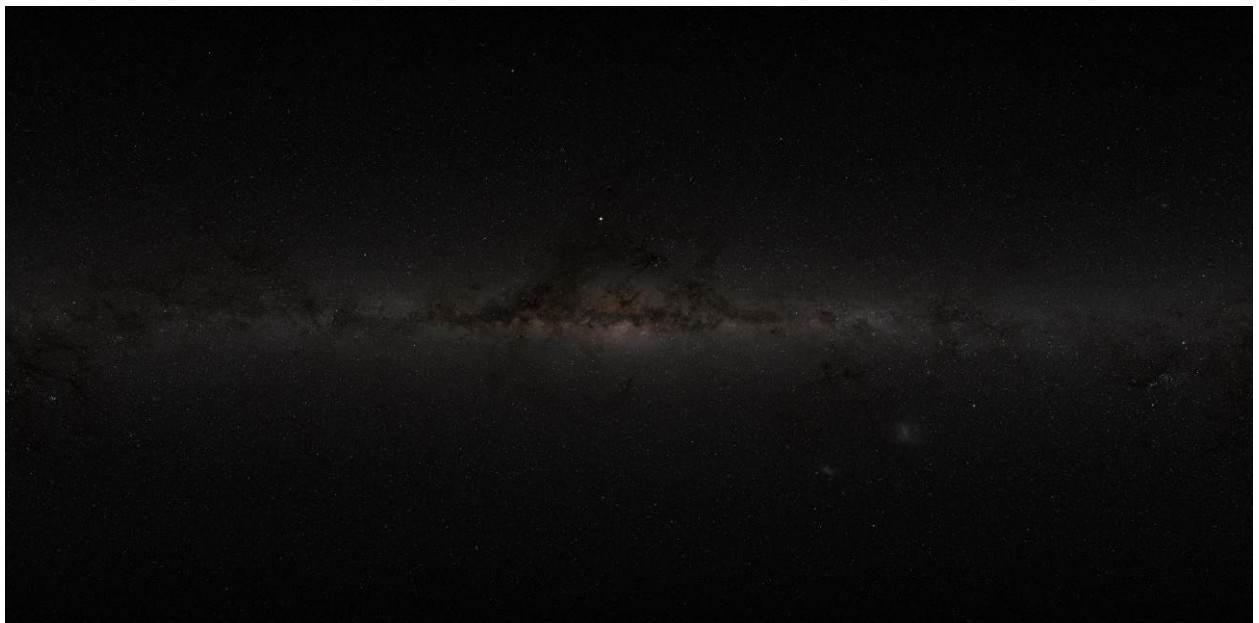
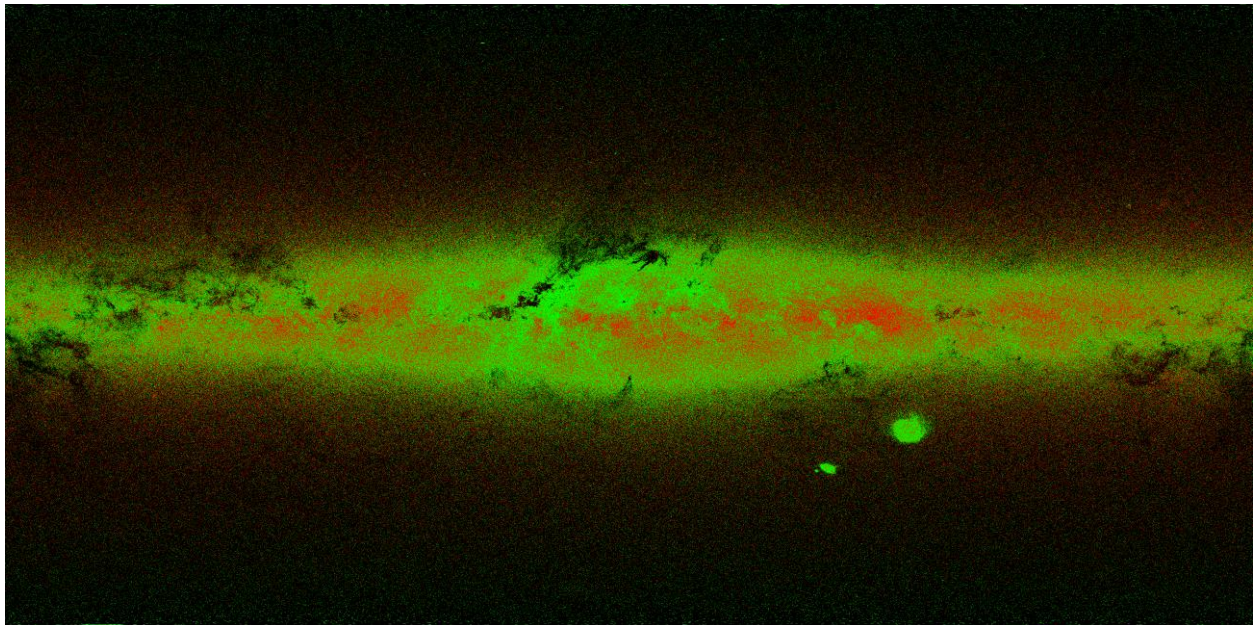
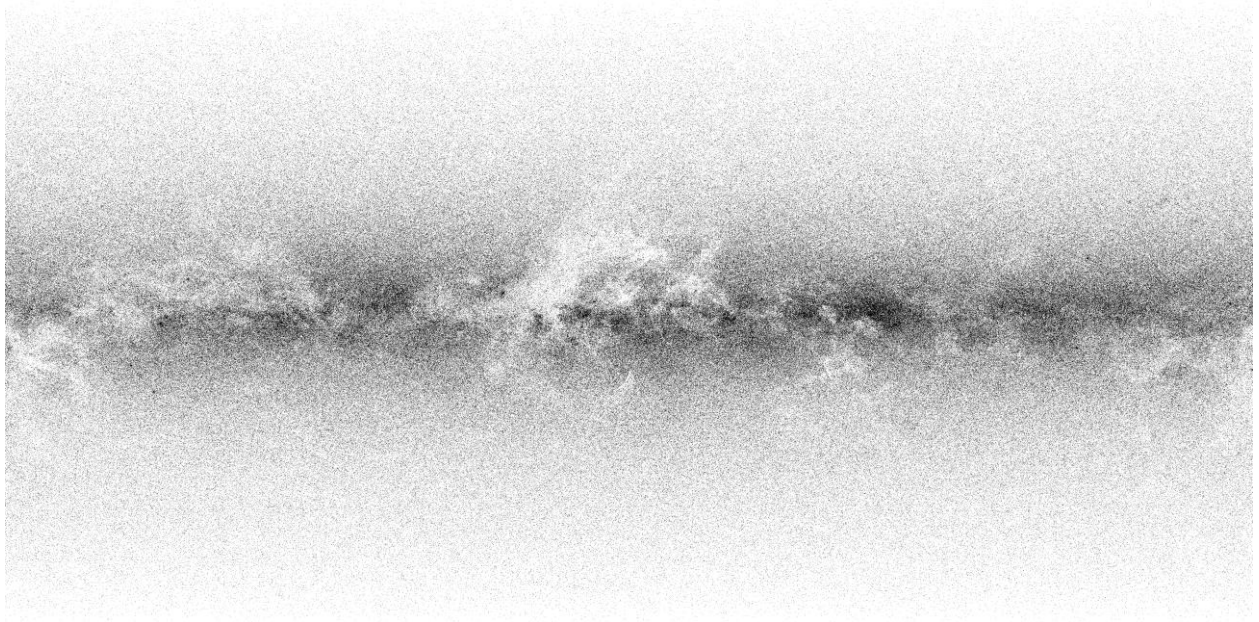
Dependency baselines include Python 3.13.14, NumPy 2.5.1, pyerfa 2.0.1.5 / ERFA 2.0.1 / SOFA 20231011, SQLite 3.50.4 and OpenImageIO 3.1.15.0 as applicable.

D.2 External scientific references

- [R1] [IAU SOFA / ERFA](#) — Astrometric state vectors, proper-motion conventions and Earth/Sun ephemeris.
- [R2] [IAU SOFA Astrometry Tools cookbook](#) — Reference frames and observer-vector astrometry.
- [R3] [Lindegren et al. 2021, A&A 649, A2](#) — Gaia EDR3 astrometric solution and conventions.
- [R4] [Bailer-Jones et al. 2021, AJ 161, 147](#) — EDR3 geometric and photogeometric distance posteriors.
- [R5] [Akeson et al. 2021, AJ 162, 14](#) — Alpha Centauri AB barycentric astrometry and relative orbit.
- [R6] [Willmer 2018 solar photometry](#) — Solar absolute visual magnitude and colour reference.
- [R7] [Ballesteros 2012, arXiv:1201.1809](#) — Approximate colour-index to blackbody-temperature relation.
- [R8] [NASA/GSFC SVS Deep Star Maps 2020, ID 4851](#) — Reference source families, projection, foreground/background separation and completeness additions.
- [R9] [CDS VizieR catalogue services](#) — Hipparcos, Tycho-2, TDSC, XHIP and Yale BSC catalogue documentation.

D.3 Controlled evidence records

The primary evidence set is the CB01–CB05 SQLite databases, schemas, summaries, provenance JSON, reports, processing histories, acceptance metrics, change logs and SHA256SUMS manifests. This narrative must never replace those records. In any discrepancy, the accepted hash-bound database and runner define what was actually computed; the document must then be corrected and re-versioned.



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