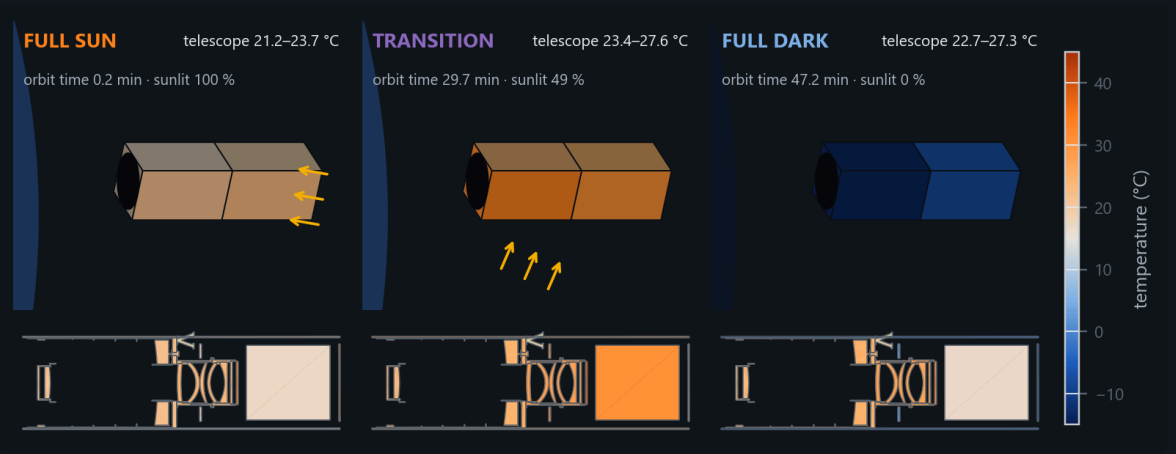
PARAXIAL CAPABILITY STUDY · FOUR CASE STUDIES · REVISION 2.1 · OCTOBER 2026

A 3U Earth-observation telescope, end to end in Paraxial

Optical design, opto-mechanical CAD and FEA, stray light and ghosts, vibration, and the satellite in orbit: one telescope taken from first-order layout to its image in orbit, entirely in Paraxial: one model, one sign-in, one SDK, with no hand-off between tools.



700 mm
f/8.1 RC telescope, diffraction-limited to the corner

-20 / +5 µm
focus change at −50 / +50 °C

6.6 %
stray light around a satellite glint

0.15 px
line-of-sight walk through an orbit

This deck is a study of the capabilities of Paraxial. All the physics has been verified against published papers, open-sourced calculations and commercial software where allowed.

BACKGROUND

What this study is, and what it is not

Commercial Earth-observation CubeSats carry a small reflecting telescope in a 10 × 10 × 34 cm body. The design questions that decide whether it works span four disciplines that are usually done in four different tools: lens design, mechanical CAD and FEA, non-sequential stray light, and orbital thermal analysis.

The question: can one platform carry a single telescope through all four, with real physics at every step and scripts that reproduce every number?

> This deck is a study of the capabilities of Paraxial. All the physics has been verified against published papers, open-sourced calculations and commercial software where allowed. The telescope, its requirements and its satellite are generic: derived from public data, not from any operator.

CS1 · Sequential design

Requirements from public data; a Ritchey–Chrétien with a five-lens flat-field corrector, diffraction-limited across the field.

CS2 · CAD mounts and FEA

Buildable, passively athermal aluminium mounts; FEA and structural-thermal-optical (STOP) proof.

CS3 · Stray light and jitter

Sun and satellite glints, the strongest ghost, baffle iteration, reaction-wheel vibration.

CS4 · The telescope in orbit

Full sun, the light/dark transition and eclipse: temperatures carried through FEA to the image.

Every case study has its own PDF report, its Python scripts (Paraxial SDK) and the raw API responses, so any number here can be re-run. Revision 2 redesigned the corrector for a flat field; revision 2.1 re-optimised it for mountable lens edges, added detailed mounts (primary flexures, lens cells, seats, spacers and retaining rings) and re-ran all four studies.

HOW IT WAS DONE

Every engine, one platform, one model

1 Optical design
One optic: prescription, damped-least-squares optimiser, paraxial data, FFT MTF, spot, Strehl, wavefront, distortion, footprints.

2 CAD and FEA
CAD parts imported into the same project, optical faces tagged by geometry, meshed (Tet4/Tet10), then modal, thermal-soak and random-vibration studies.

3 STOP
FEA displacements fitted with Zernike figures and applied to the same optic: line of sight, focus and MTF of the deformed telescope.

4 Stray light
The non-sequential scene built from that optic and its CAD: glint sweeps, ghost ranking, point-source transmittance, coatings and surface finishes.

5 Orbital thermal
Orbit environment, absorbed flux and a transient over four orbits; temperatures mapped straight onto the FEA mesh and on into STOP.

- **Computed in Paraxial.** Every ray trace, MTF, mesh, FEA solve, Zernike surface fit, STOP analysis, non-sequential trace and orbital-thermal result in this deck is a Paraxial API response, saved next to the script that requested it.
- **One model, one frame.** The FEA study, the stray-light scene and the thermal model all refer to the same optic in the same project, in Paraxial's lens frame. There is no export to a CAD, FEA or stray-light package and no re-import, so no units or coordinate systems get lost between vendors' tools.
- **One sign-in, one licence, one SDK.** All five disciplines run through one authenticated Python session.
- **Checked inside the platform.** Results are cross-checked with a second Paraxial method, e.g. STOP focus against a detector scan and a sequential re-trace of the deformed design.

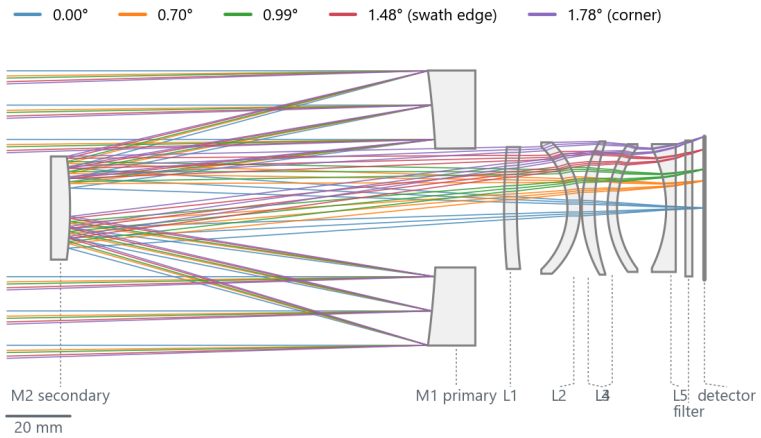
What the scripts add: the parametric CAD is drawn in Paraxial's lens frame (CadQuery) from the API prescription and uploaded once; the scripts also fit each optic's rigid-body motion to the FEA displacement table, add up the CS4 focus terms and draw the figures from the saved responses. The corrector layouts were first explored on a local tracer; the final designs were built and verified in Paraxial.

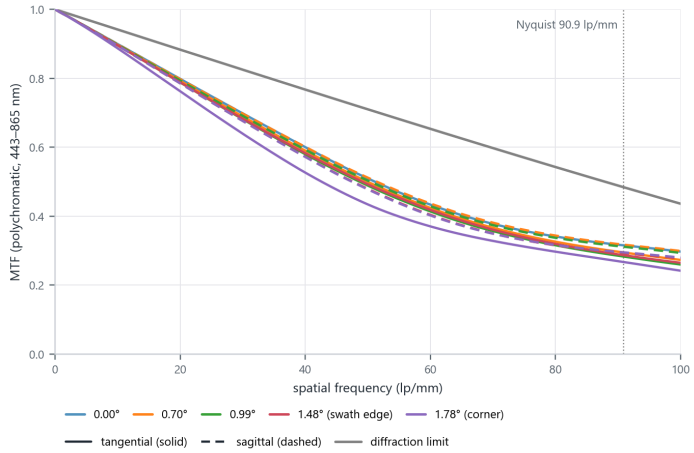
CASE STUDY 1 · SEQUENTIAL OPTICAL DESIGN

A diffraction-limited 700 mm telescope in 3U

- **Requirements from public data:** 3.7 m per pixel from 475 km with 5.5 µm pixels, so a 700 mm focal length; 86 mm aperture (f/8.1); a 2.9° × 2.0° field; eight bands, 443–865 nm.
- **Design:** hyperbolic primary and secondary, 115 mm apart; a three-lens front corrector and two negative field flatteners before the stripe filter, all spherical, in two flight glasses.
- **Image quality (FFT MTF at Nyquist):** 0.32 on axis and 0.27 / 0.29 (T/S) at the corner; at least 0.27 everywhere. Diffraction-limited from the centre to the corner.

> **Revisions 2 and 2.1:** the first design was limited by field curvature (0.03 on axis, about zero at the corner). The mirrors' Petzval sum can only be cancelled by negative lens power near the image, so two field flatteners were added; revision 2.1 kept every lens edge ≥ 1 mm at its mounting rim.





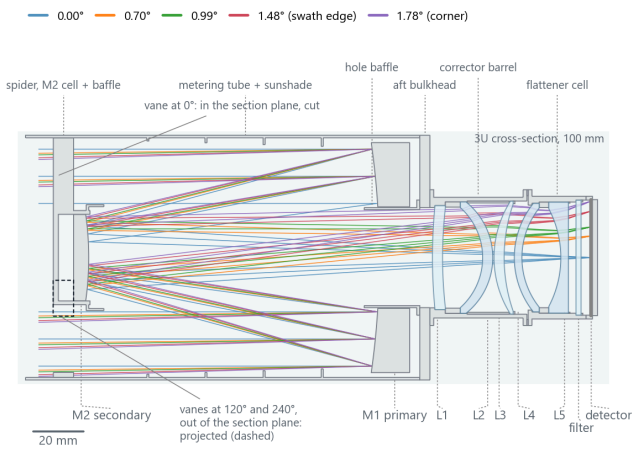
700.0 mm	f/8.13	3.73 m	3.1 %
focal length	focal ratio	ground sample	distortion (target 3 %)

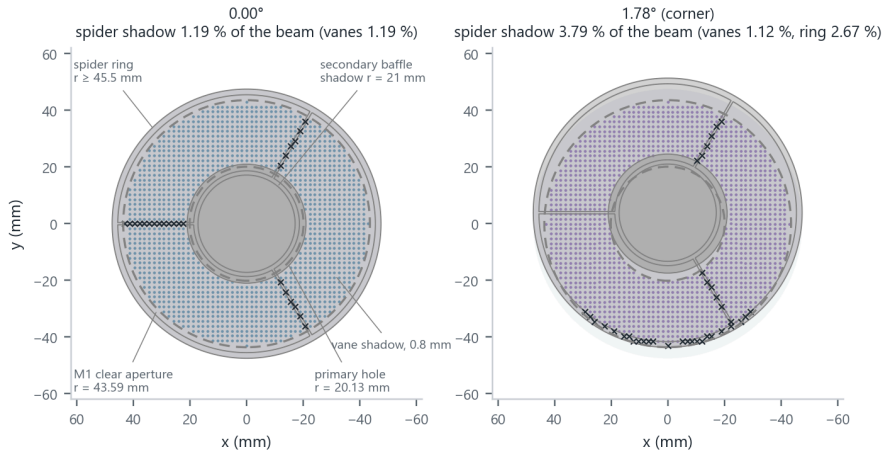
CASE STUDY 2 · CAD MOUNTS, PART 1

Real mounts, drawn from the CAD

- **All-aluminium (homologous):** diamond-turned RSA-6061 mirrors in an Al 6061-T6 tube, on three titanium bipods. The CAD is a set of STEP parts.
- **Secondary on a three-vane spider** (0°, 120°, 240°), 0.8 mm thick, with a 21 mm baffle.
- **Obscuration measured, not estimated:** the vanes block 1.2 % of the beam. The spider ring clips 2.7 % at the field corner; the fix (open its bore to 47.5 mm) is identified.

1.2 %	2.7 %	635 g	1252 Hz
beam lost to the vanes	corner clip by the ring	mechanics and mirrors	first mode



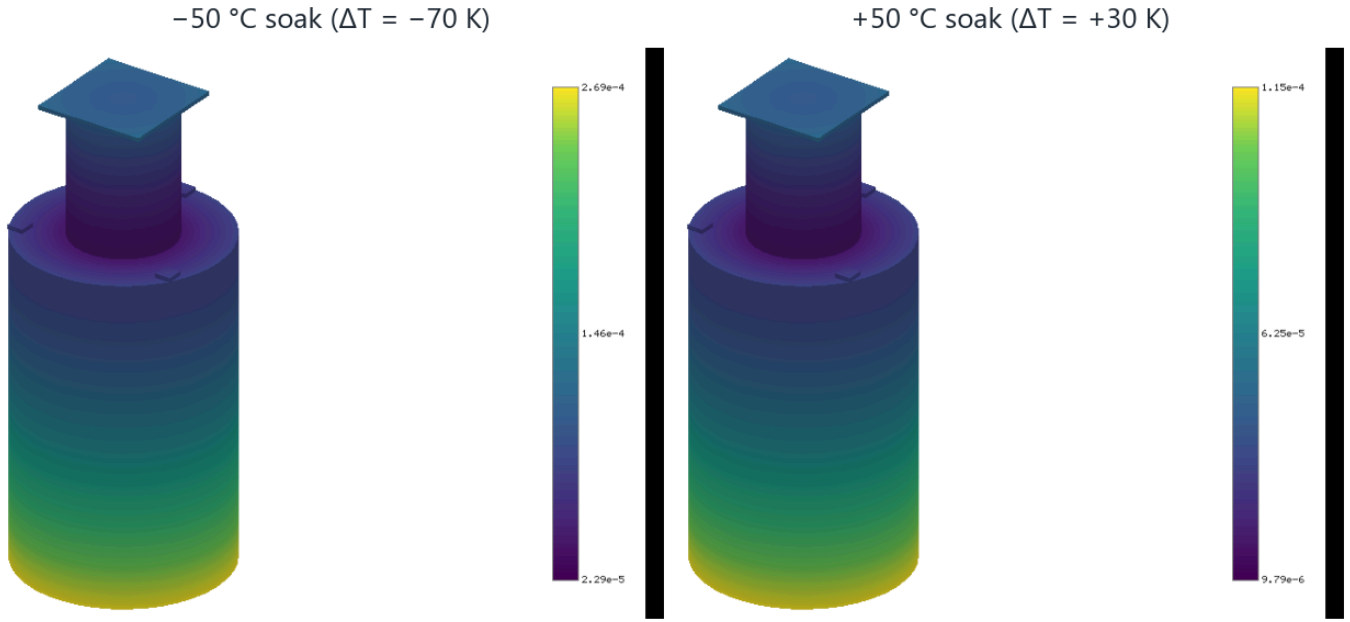


CASE STUDY 2 · CAD MOUNTS, PART 2

A uniform −50 to +50 °C soak stays in focus

- **FEA soak:** the CAD meshed in Paraxial, cooled to −50 °C and warmed to +50 °C, held at the bipod lugs.
- **Homologous, as designed:** every optical face scales by the same factor in the FEA, so the design re-traced at that scale gives focus and sharpness; STOP gives the line of sight.
- **Result:** best focus moves -20 µm cold and +5 µm hot, against a ±75 µm depth of focus, and the MTF at Nyquist changes by at most 0.012. Low-expansion glass mirrors in a metal or composite tube would move it 117–5736 µm.
- **Kinematic:** support reactions are around 10^{-7} N, so the mount adds no thermal stress.

> **Decision:** build the telescope all-aluminium. It is the only option that stays in focus through a *uniform* temperature change without a refocus mechanism. A primary at a different temperature from its tube is a different load: see case study 4.



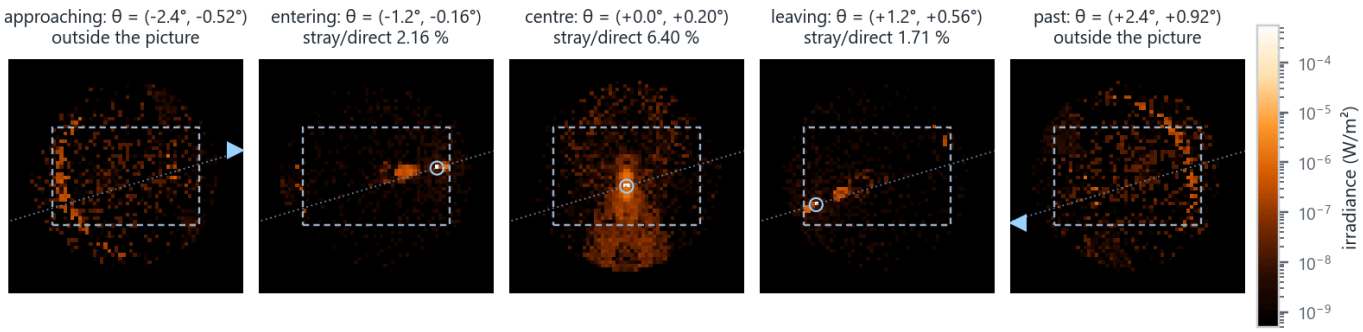
Paraxial structural engine: displacement in the −70 K and +30 K soaks.

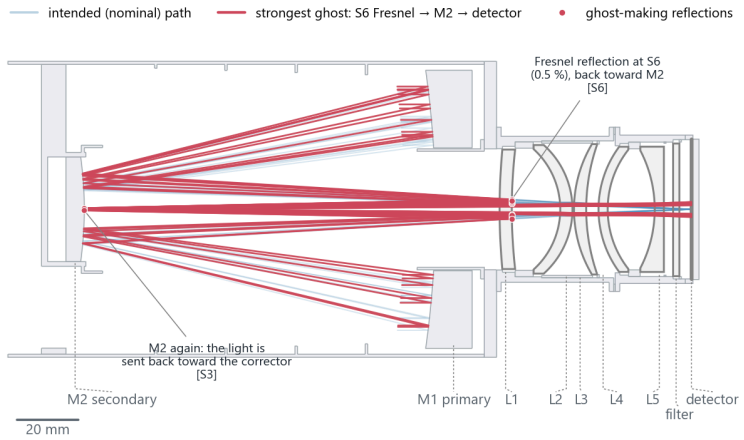
CASE STUDY 3 · STRAY LIGHT, PART 1

A satellite glint, and the strongest ghost

- **Satellite glint crossing the field** (31 positions): inside the picture the stray light is 0.56–6.65 % of the glint's image.
- **Just outside the field** 1–4 % of its light still reaches the sensor: it misses the secondary and goes straight down the primary hole.
- **Strongest ghost:** one Fresnel reflection at the first corrector lens (S6), sent back by the secondary: 0.951 % of the image, just over the 0.1 % target. Five lenses make more ghosts than three; a better AR on that one lens is the fix.

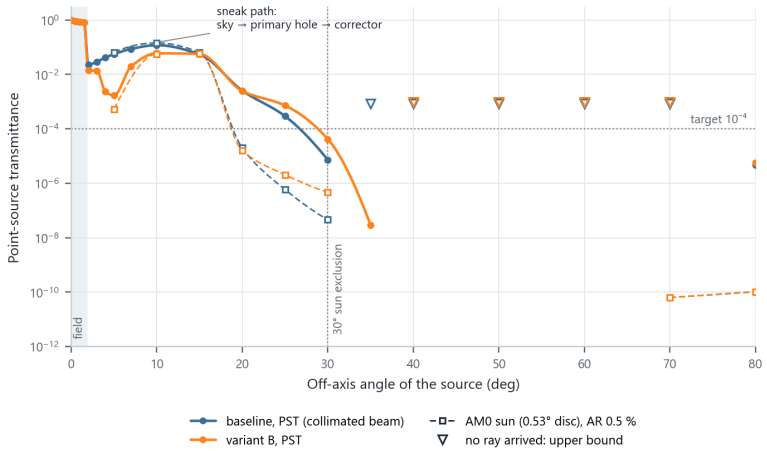
> **Finding:** the primary-hole sneak path is the telescope's main stray-light weakness, both for glints and for the sun at 2–15°.

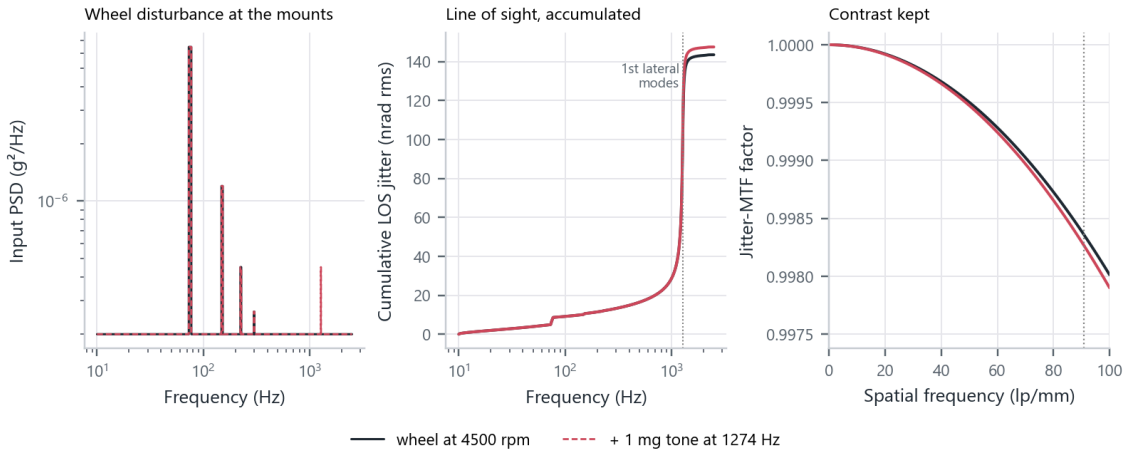




The sun out of field, and a reaction wheel

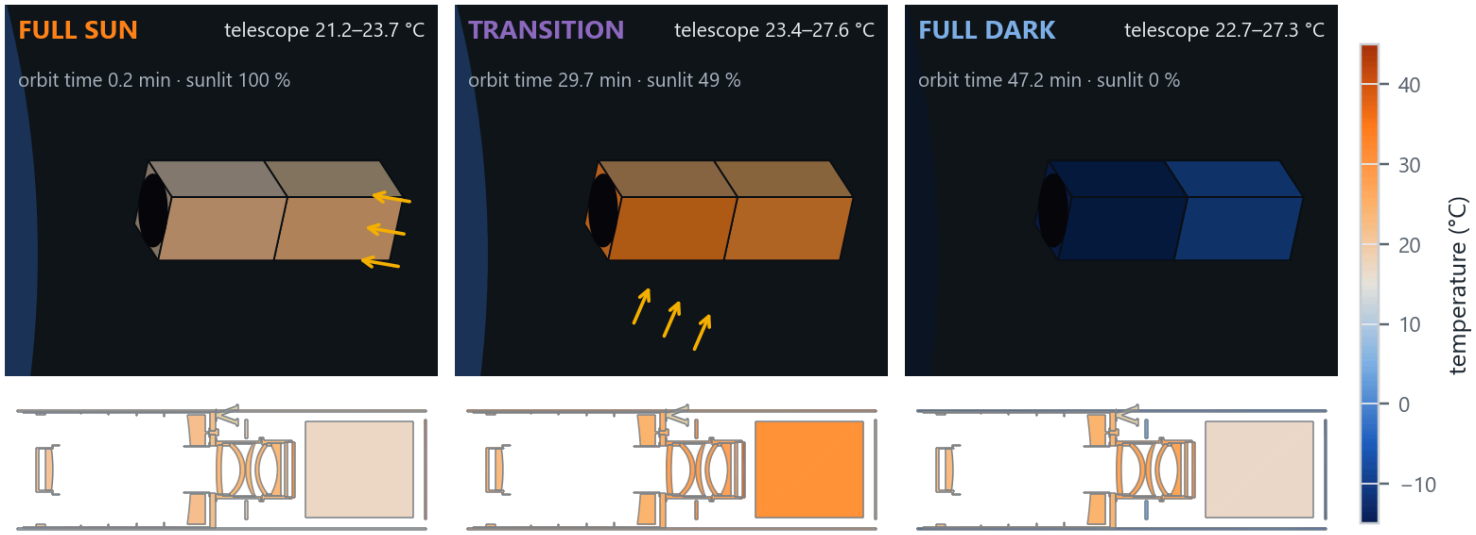
- **Point-source transmittance:** up to 0.12 at 10° (the sneak path). A larger secondary baffle with a 30 mm hole baffle cuts 5° from 6e-02 to 2e-03, at a cost in on-axis contrast (larger obscuration).
- **Sun beyond 25°:** rejected to 10^{-5}–10^{-7}.
- **Reaction-wheel jitter** (random-vibration FEA → STOP line of sight): 143 nrad rms, set by the bearing noise at the 1274 Hz lateral mode. It costs 0.174 % of contrast at Nyquist; spacecraft pointing jitter, not the telescope, is the term to budget.





Full sun, the terminator and eclipse

- **The satellite in orbit:** 3U CubeSat, 500 km, nadir pointing, 37 % of each orbit in eclipse, with sun, Earth-reflected light and Earth infrared on every face.
- **The shell swings, the telescope does not:** the panels go from -25 to 34 °C each orbit; the tube and mirrors stay at 20–28 °C behind low-emittance tape and titanium bipods.
- **The warmest moment is the transition** into eclipse; the telescope lags the panels by tens of minutes.

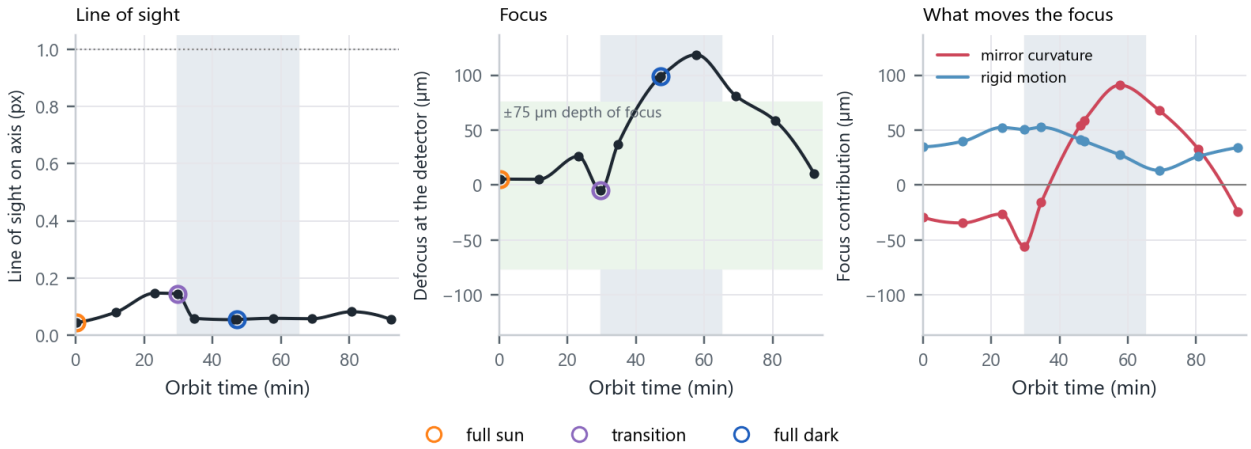


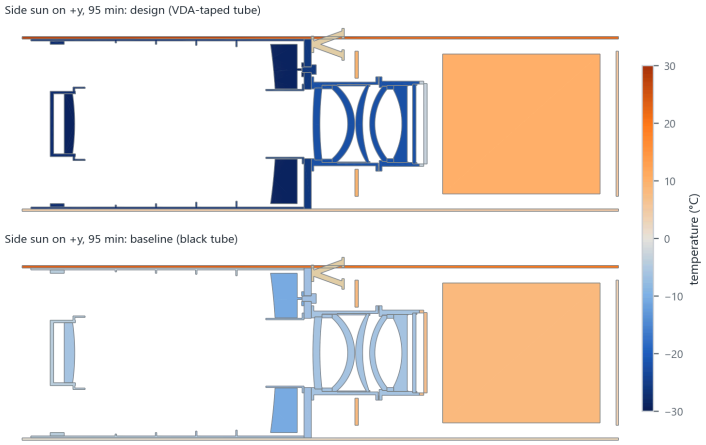
Payload temperature at the three moments: the satellite from outside, with the sun's direction, and the section through the telescope.

The primary against its tube sets the focus

- **Through the orbit** (thermal → FEA → STOP at 11 instants): line of sight under 0.15 px; focus -5 to +119 µm against a ±75 µm depth of focus.
- **Uniform is harmless, a mismatch is not:** when the whole telescope warms 1 K the focus moves +0.7 µm (the CS2 result); when only the primary warms 1 K it moves +51 µm. In eclipse the primary runs up to 2.1 K warmer than the tube, which is the whole focus swing. Refocused, the image is still diffraction-limited (≤ 0.74 µm RMS on axis).
- **Sun held on one side:** the taped tube keeps the line of sight at 0.07 px (black tube 1.8 px); focus reaches -88 µm (black tube -450 µm).

> **Decision:** hold the primary within about 1.5 K of the tube (a conductive strap or matched coatings) and keep the low-emittance tape. A detector stage of about 119 µm is the fallback.





SUMMARY

One telescope, four disciplines, one platform

STUDY	DISCIPLINE	HEADLINE	OPEN ITEM	STATUS
CS1	Optical design	`700 mm, f/8.1; MTF at Nyquist ≥ 0.27 to the corner`	Distortion 3.1 % (target 3 %); tolerancing	◐ Partly
CS2	Mounts and FEA	`Focus -20 / +5 µm over −50 to +50 °C`	Spider ring clips 2.7 % at the corner (fix found)	✓ Met
CS3	Stray light and jitter	`Glint ≤ 6.6 %, ghost 0.951 %, jitter 143 nrad`	Primary-hole sneak path, 2–15° and just outside the field	◐ Partly
CS4	Orbit STOP	`Telescope 20–28 °C, ≤ 0.15 px`	Focus -5 to +119 µm: hold the primary within 1.5 K of the tube	◐ Partly

One platform, end to end

The same optic and CAD flowed from lens design to FEA, stray light and orbit inside one Paraxial project: one licence, no exports between tools, no lost frames.

Real physics, quoted honestly

Monte Carlo error bars, published sampling, independent cross-checks of key numbers, and corrections stated where an earlier number was wrong.

Reproducible

Every number comes from an API response saved with the scripts that made it; each study re-runs from its README.

Fast

A redesign carried through all four studies in about 3.5 h of agent time and 3.5 h of API compute; weeks of traditional engineering, done in an evening.

This deck is a study of the capabilities of Paraxial. All the physics has been verified against published papers, open-sourced calculations and commercial software where allowed. Platform issues found along the way are listed in each report and in CASE_STUDIES_README.md.