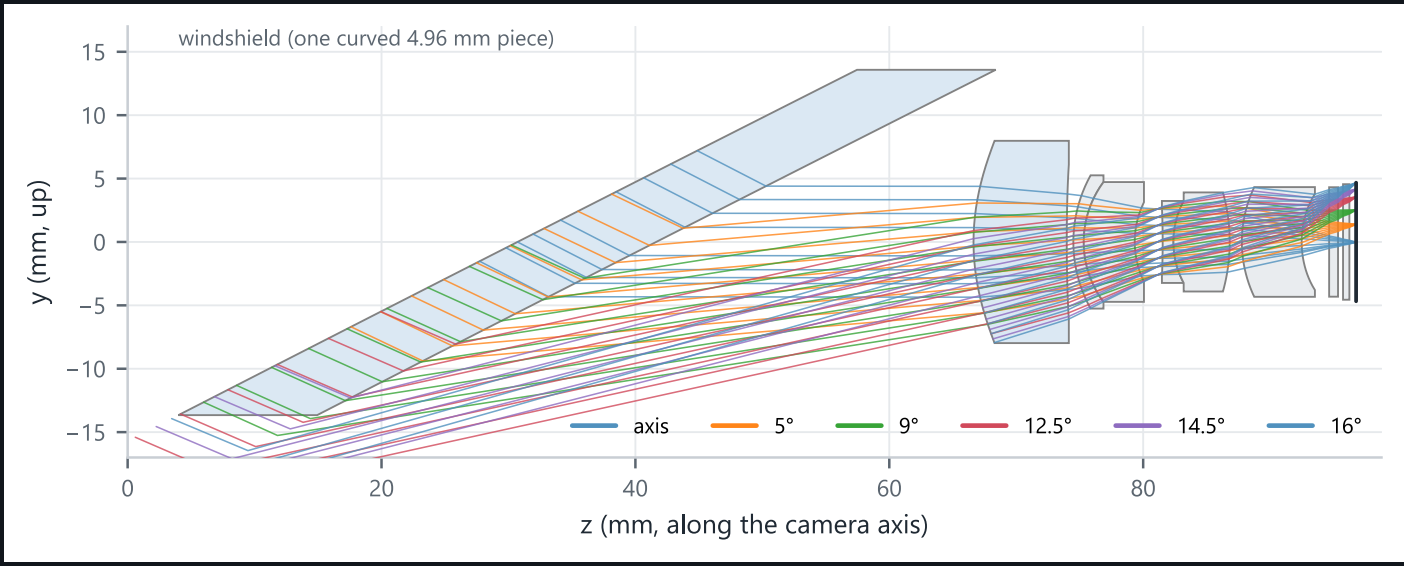
CASE STUDY 3 · VISION-ONLY CAR · 31 OCTOBER 2026

Sun, glare and night for the far stereo camera

The far stereo pair looks out through the raked windshield into the low sun, the oncoming low beams and the dark. This study puts the CS1 far lens behind a curved windshield at a 63° rake and asks what the glass does to the image, how much sunlight and headlamp light ends up as glare on the sensor, what removes it, and whether the car's own low beams light a pedestrian well enough at night. Every optical number comes from the Paraxial API.



The far lens behind the curved windshield (one 4.96 mm biconic piece, 63° from vertical), rays for six fields (Paraxial layout endpoint).

38×
less sun glare with the sun in the picture,
coated and blackened vs as designed

183×
less stray light with the sun 16–40°
above the picture, coated and blackened

150 m
farthest range at which a dark-clad
pedestrian's legs clear SNR 5 at night

Paraxial · fea deployment · project “Vision-Only Car Demo”

THE WINDSHIELD 01

What the glass does to the image

The windshield is curved, as a car's is: a biconic surface with a 3000 mm radius across the car and 10000 mm up the glass, raked 63° from vertical, 25 mm in front of the lens. The inner face is concentric with the outer, so the glass is a uniform 4.96 mm thick: the 2.1 + 0.76 + 2.1 mm of a typical laminate (research), traced as one piece: the PVB (n ≈ 1.48) against soda-lime (1.52) reflects about 0.02 % per face, 200 times less than an air–glass face. It is a surface model, not a CAD part: a biconic is the exact shape of a windshield patch with two principal curvatures, and both the sequential trace and the non-sequential promotion carry it. Clear, never tinted (kick-off); the object stays at 250 m. Every sun and headlamp run carries the lens barrel (common/housing.py), so light reaches the sensor only through the lens; revision 2's automatic housing, one cylinder as wide as the windshield, let light pass outside the small elements.

Over the 6 mm beam the curved glass is a tilted parallel plate to well under a wavelength, which shifts the image but adds no blur; the API's FFT MTF agrees: on axis 0.820 behind the glass against 0.821 bare. The Huygens MTF reports 0.700, a drop the physics does not support (platform notes); the FFT values are the ones used.

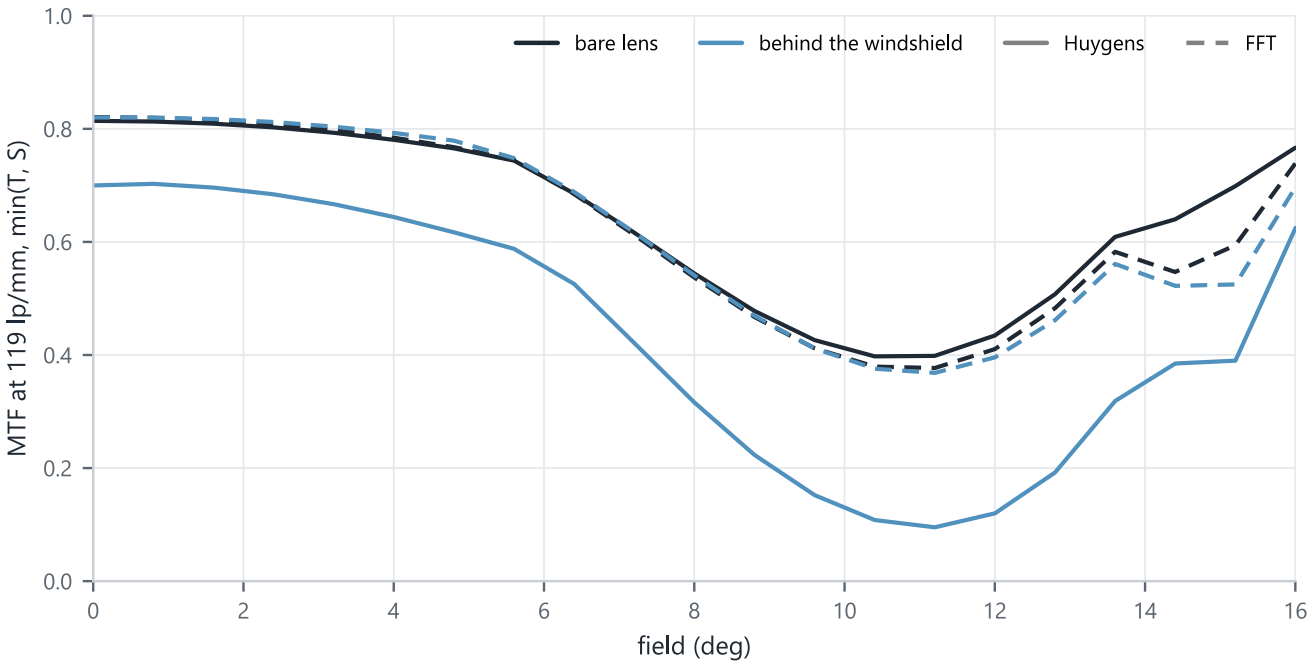


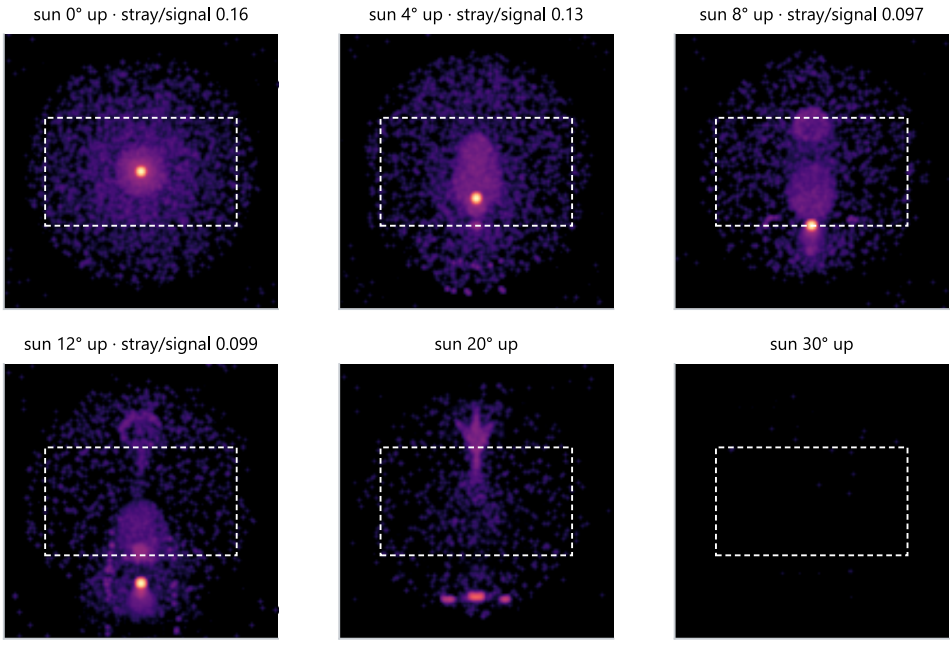
Figure 1. MTF at 119 lp/mm (half Nyquist) across the field, bare and behind the windshield; Huygens solid, FFT dashed.

The window-ghost analysis finds the windshield's double image (reflected inside the glass from the inner face to the outer and forward again) at 0.93 % of the image: a faint second copy of a bright scene, not glare.

THE SUN 02

Glare from a low sun

The sun is placed 0–40° above the far camera's axis (the picture's top edge is 8°, its corner 16°) and traced non-sequentially with every Fresnel reflection the faces make: AM1.5G sunlight, 400–700 nm, 430 W/m² at the glass (the API's standard). The result is the stray light that lands on the sensor, with the sun's own image excluded. To give it a scale it is compared with the image of a sunlit white target, $E \cdot T/(4N^2)$ = 10.1 W/m² through the uncoated lens and 18.4 W/m² through a coated one (local arithmetic on the API's f/# and transmittance): glare above 5 % of that (a decision) veils a dark road.



Log irradiance on the image-plane pad (5 decades), direct image plus stray, 200,000 rays per frame, smoothed 0.7 px, one scale for all six; dashed: the sensor. The sun leaves the picture above 8°.

Figure 2. The sun climbing through the far camera's view behind the windshield: direct image and stray light on the image plane, 200,000 rays per frame, one log scale for all six. A video of the full sweep is figures/sun_sweep.mp4.

What the flare looks like. With the sun in the picture its image carries a wide, soft bloom, the light scattered into the halo by the faces' Fresnel reflections, and across the optical axis from it, at the point-symmetric position, sits a second, fainter image drawn out into a comet-like tail: the two-reflection ghost, focused short of the sensor by the extra curved reflections and smeared radially by the coma those off-axis bounces add. As the sun climbs the two move apart symmetrically about the axis, the bloom toward the bottom of the picture and the ghost toward the top (the image is inverted). At 4–12° the ghost is still on the sensor while the sun's own image has left it; above about 20° only a faint arc from rays skimming the barrel's front lip remains.

As designed the lens is uncoated, which is how the API models it until a coating is assigned. With the sun in the picture the stray light is 373 % of a white target, almost all of it two-reflection ghosts between lens faces. A second, weaker band appears with the sun 16–26° above the axis, outside the picture, at up to 11.1 W/m² on the active area. Here ghosts are the minority: the API's path attribution finds that at 16–18° most of it reaches the sensor without a single Fresnel reflection, turned by total internal reflection

at the ground edge of an N-BK7 element near the rear of the lens. At 20–24° a further share enters through the cut edge of the modelled windshield patch (60 mm across) and is guided inside the glass by total internal reflection; a real windshield has no edge there, so that share is an artefact of the finite patch and the band above 20° is an upper bound.

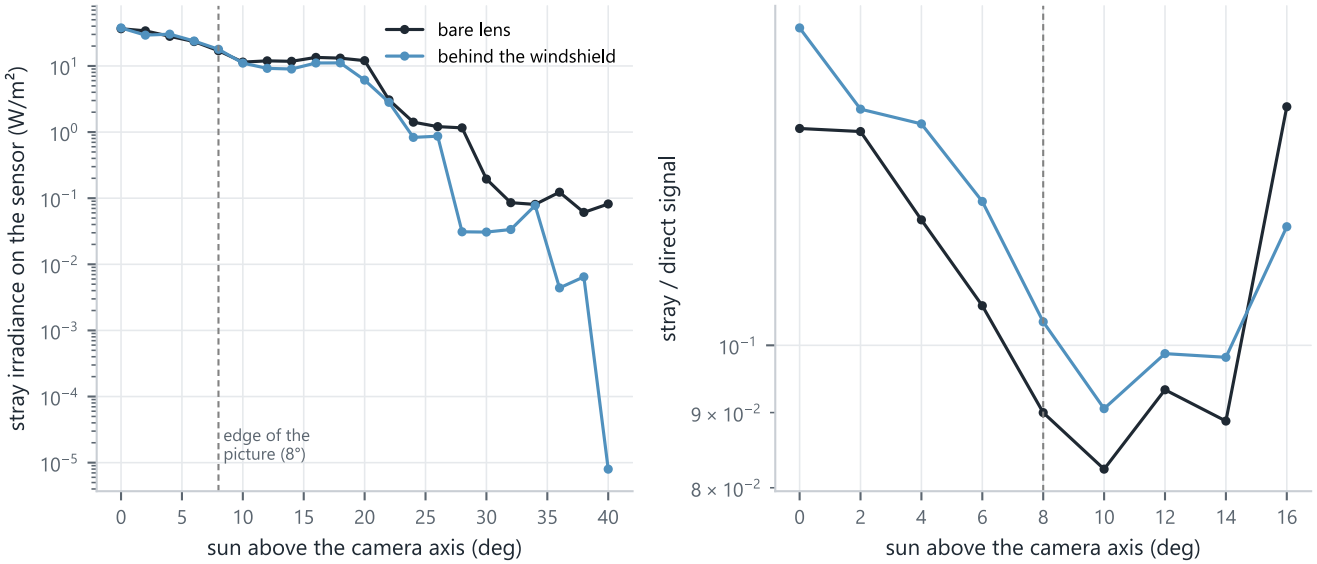


Figure 3. Stray irradiance on the sensor against sun elevation, bare lens and behind the windshield, and stray over the sun's direct image while it is in the picture.

What removes it

Each fix was run as a variant of the same model:

DESIGN	SUN ON AXIS (W/M²)	OF WHITE TARGET	WORST, SUN 16–40° (W/M²)	OF WHITE TARGET
As designed: uncoated lens	37.64	373 %	11.13	110 %
Lens MgF_2 single layer	8.04	80 %	2.98	30 %
Lens AR 0.5 % per face	5.88	32 %	2.87	16 %
Glare shield at the lens	36.41	360 %	11.13	110 %
AR 0.5 % + glare shield	5.59	30 %	2.85	15 %
Lens edges blackened	35.20	349 %	2.56	25 %
Edges blackened + AR 0.5 % on every face	0.99	5 %	0.06	0 %

A lens AR coating cuts the in-picture ghosts about fourfold; what remains is mostly the windshield's own double reflection. A glare shield in front of the lens does nothing for either band. With the sun above the picture the AR coating does most of the work (11.1 → 2.87 W/m²); blackening the element edges, a standard ink step in lens assembly, alone gives 11.1 → 2.6 W/m² and takes out the edge path (11.1 → 2.5 W/m² at 18–22°). Together with a 0.5 % AR on every glass face, including the camera's patch

of the inner windshield, the glare falls to 5.3 % of a white target with the sun in the picture and 0.3 % above it.

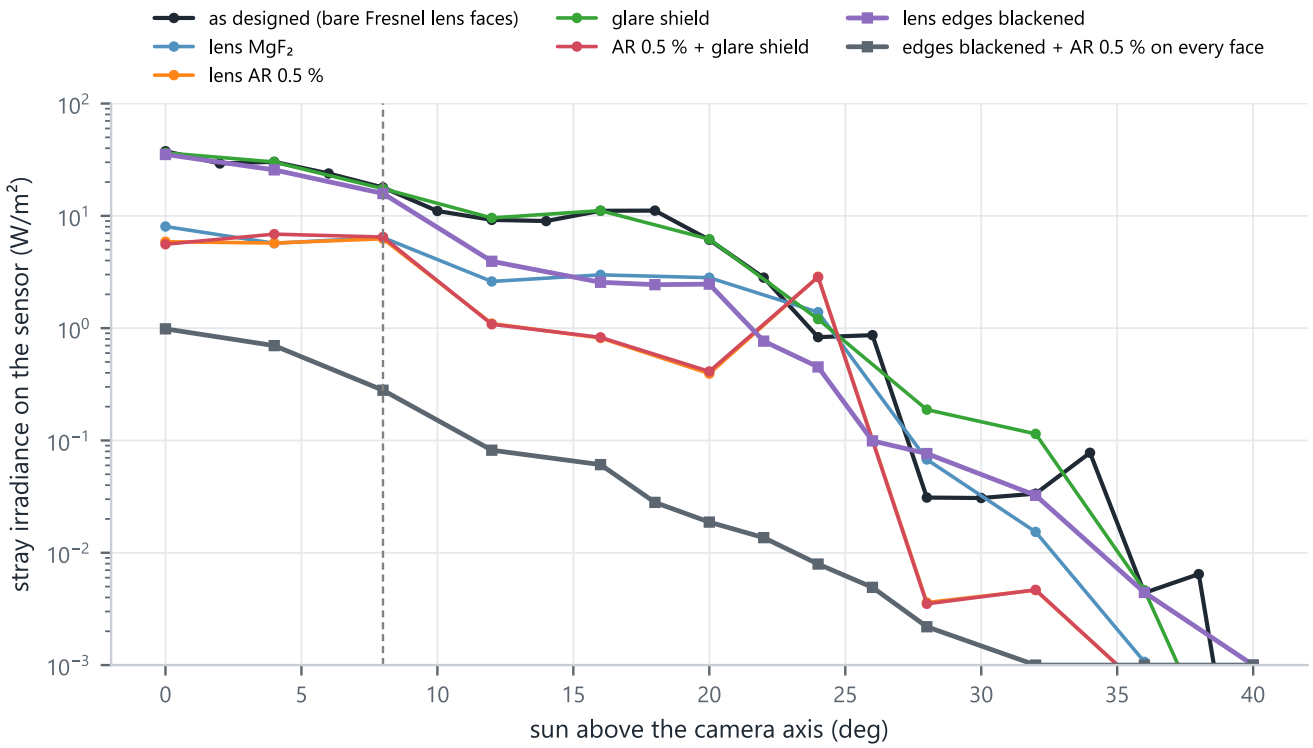


Figure 4. Stray irradiance on the sensor for every variant.

NIGHT 03

Low beams, oncoming glare and a pedestrian

Oncoming headlamps. An oncoming car's two low beams (UN R112 B50L point, 350 cd each) are placed at 10–150 m in the next lane. At 10 m they are outside the far camera's picture; from 25 m in, the stray light around each lamp's image is 0.09–0.14 of the lamp image itself, a halo and its ghost across the axis rather than a veil. It is highest at 100 m, where the lamps' images sit nearest the axis and their ghosts overlap them; an AR-coated lens cuts it about fourfold, as it does the sun's ghosts.

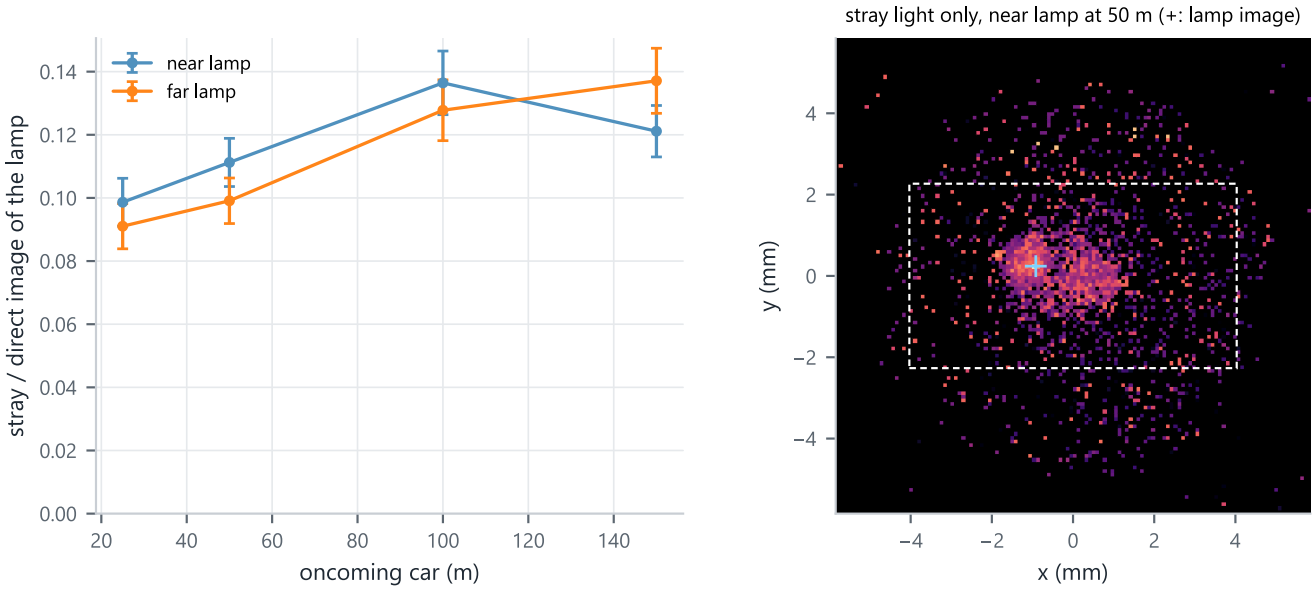


Figure 5. Stray light over the lamp's direct image against range, and the stray-light image at 50 m: the lamp's own halo and a ghost of it across the axis.

Seeing a pedestrian by the car's own low beams. A pedestrian in dark clothing (6 % reflectance) straight ahead is lit only by this car's low beams at the regulation minima. The camera equation uses the API's working f/1.84, relative illumination, and the transmittance of every face (windshield 61 % at 63°, uncoated lens 52 %, coated 95 %), with a public automotive sensor's green-pixel response and read noise (local arithmetic, cs3_night.py).

Per pixel the signal is small (SNR 1.8 at 50 m), but a detector pools the pixels on the target: the legs, below the beam's cut-off, clear a pooled SNR of 5 out to 150 m with a coated lens. The torso is above the cut-off and gets at most the glare-zone limit; it clears 5 only to 75 m. An oncoming car at 50 m adds 0.058 lux of halo where the pedestrian is imaged, and the legs' per-pixel SNR at 50 m falls from 1.77 to 0.74.

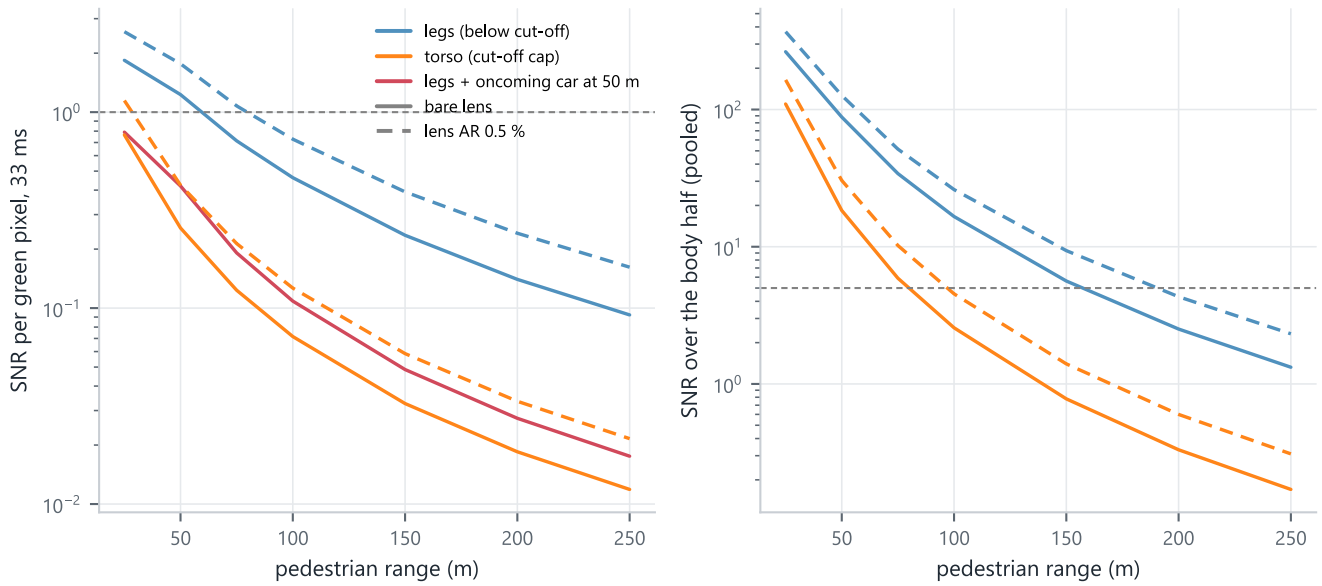


Figure 6. Night SNR of a dark-clad pedestrian against range: per green pixel (left) and pooled over the body half (right); 33 ms exposure.

RECOMMENDATIONS 04

What the design should do

- **Coat everything.** A 0.5 % AR on every lens face is the largest single gain in the sun and adds 83 % more light at night.
- **Blacken the element edges.** Cheap insurance: with the lens coated it takes the remaining stray with the sun above the picture from 2.87 to 0.06 W/m², and it closes the edge path.
- **AR-coat the camera's patch of the inner windshield.** With the lens coated, the windshield's double reflection is what remains of the in-picture glare.
- **Skip the glare shield.** It changes neither band for this camera.
- **Night reach is set by the beam pattern.** The legs are visible to 150 m, the torso only to 75 m; a lower-noise sensor or longer exposure helps less than the beam's own cut-off.

METHOD 05

How the numbers were made

Every optical number is a saved Paraxial API response; the full report adds the method detail.