

# 337 nm CubeSat photometer

Technical assessment: photon transfer, backgrounds, receiver and validation

**22 October 2026 | Standalone revision r4**

Source altitude 15-18 km; nominal orbit 550 km; simultaneous 337 nm and 777 nm channels.

Measured evidence, conditional calculations and unresolved mission inputs are labeled separately. This document replaces the interpretation of earlier layered revisions.

**Fresh finite-cylinder nonspherical-ice calculations were executed. Numerical convergence remains incomplete in flagged cases; they are diagnostics, not validated predictions of real anvil timing.**

The original question numbering is retained. Initial denotes the unnumbered transmission question; A-1 is the tool question and A-2 is the timing question; B-4 through G-22 follow the original list.

# Contents

|                                                                                                  |    |
|--------------------------------------------------------------------------------------------------|----|
| Contents                                                                                         | 2  |
| Scope and how to read the evidence                                                               | 4  |
| What is established, and what remains a measurement . . . . .                                    | 4  |
| The 22 original questions                                                                        | 5  |
| Initial question - Transmission to nadir at 550 km versus overhead cloud optical dept... . . . . | 5  |
| A-1 - Which radiative-transfer calculation/tool should be used, and alternatives to C... . . . . | 6  |
| A-2 - Multiple scattering and temporal profile; robustness of 30-80 us versus>200 us ... . . . . | 6  |
| B-4 - Absolute nightside 337 nm radiance: quiet airglow, moon, zodiacal light and int... . . . . | 7  |
| B-5 - Auroral 337 nm 4 nm-band brightness and shot-noise floor during moderate/distur... . . . . | 8  |
| B-6 - Lunar phase/elevation at which cloud background dominates detector noise. . . . .          | 9  |
| C-7 - Detector choice at 337 nm, large area and 10-50 kHz; claimed photodiode/TIA floor. . . . . | 10 |
| C-8 - NEP and aperture photons per event for candidate detectors. . . . .                        | 10 |
| C-9 - DC coupling and preservation of a>3 ms pulse. . . . .                                      | 11 |
| C-10 - 2-3 year 550 km polar/SAA radiation effects on dark current and gain. . . . .             | 12 |
| C-11 - European suppliers for flight or near-flight detectors. . . . .                           | 13 |
| D-12 - Maximise nonimaging photometer etendue within roughly 1U. . . . .                         | 13 |
| D-13 - Maintain narrowband filter response over 60-90 degree full field. . . . .                 | 14 |
| D-14 - Is 4 nm FWHM optimal for the N2(0, 0)band and background? . . . . .                       | 15 |
| D-15 - Required optical density and rejection wavelength range. . . . .                          | 15 |
| E-16 - 777.4 nm null-channel detector and comparable photon thresholds. . . . .                  | 16 |
| E-17 - Cross-calibration of different detector technologies for a trustworthy ratio. . . . .     | 17 |
| F-18 - On-orbit gain drift, absolute radiometric stability and peak brightness versus... . . . . | 18 |
| F-19 - Ground calibration/characterisation and facilities. . . . .                               | 19 |
| F-20 - Laboratory 337 nm source with 30 us rise and>3 ms duration. . . . .                       | 19 |
| G-21 - Can 2-4 kg/5-10 W deliver a useful event rate at 550 km? . . . . .                        | 20 |
| G-22 - What assumptions or physics are missing? . . . . .                                        | 21 |
| Fresh calculations and their limits                                                              | 22 |
| R4-N01 - Clear-air direct Rayleigh transmission . . . . .                                        | 22 |
| R4-N02 - An above-top reflector can increase nadir light and delay it . . . . .                  | 23 |
| R4-N03 - Depth and diffusion strength are not uniquely identifiable . . . . .                    | 24 |
| R4-N04 - Raw dead time can compress an apparent rise . . . . .                                   | 25 |

|                                                                                        |    |
|----------------------------------------------------------------------------------------|----|
| R4-N05 - Auroral/background amplitude scenarios and exact Poisson thresholds . . . . . | 26 |
| R4-N06 - Field size versus an unknown source-brightness law . . . . .                  | 26 |
| R4-N07 - Actual reference continuum and starlight data folds . . . . .                 | 27 |
| R4-N08 - Optical/electronic design algebra with explicit assumptions . . . . .         | 27 |
| R4-N09 - Detection is easier than trusted morphology classification . . . . .          | 28 |
| R4-N10 - Exact counts, finite-baseline limits and search control . . . . .             | 29 |
| R4-N11 - Independent cylinder transport and the unresolved rare-path test . . . . .    | 30 |
| R4-N12 - Conditional transported pulse timing and electronics . . . . .                | 32 |
| Minimum remaining validation program                                                   | 34 |
| Terms and units . . . . .                                                              | 34 |
| Sources, access and applicability                                                      | 35 |

## Scope and how to read the evidence

The study concerns a nightside two-channel photometer near 550 nm, with a 337 nm nitrogen band used to detect blue streamer-like transients and a simultaneous 777 nm channel used to constrain thermal alternatives. The optical-head target is approximately 2-4 kg and 5-10 W. These are requirements under assessment, not a completed hardware design.

The strongest result is a set of corrected physical constraints and reproducible conditional tests. Molecules above 15-18 km remove several percent of the direct 337 nm beam; clouds redirect and delay light; actual photon counts and the entire receiver response govern timing and a red upper limit. The campaign has not supplied an unbiased faint-source population, a polar 337 nm background climatology or accepted flight hardware.

This is a new standalone revision. It replaces interpretation of the earlier layered technical and Physics 101 PDFs. Earlier CloudScat runs are dated conditional heritage; fresh revision analyses are identified by their execution receipts. A run is not described as measured or physically validated merely because it completed or passed algebraic checks.

The original list starts with an unnumbered transmission/Rayleigh question, then tool question 1 and timing question 2, followed by 4-22. The document preserves those scopes as Initial, A-1, A-2, B-4 through G-22. Complete-document numbers 1-22 are navigation only; no missing original question 3 is invented. All 22 scopes have reviewed answers, but the selected mission is not empirically closed.

### What is established, and what remains a measurement

A physical principle can be settled while an instrument choice remains open. A calculation can be correct under assumptions while a real cloud or source violates those assumptions. A measurement on another mission is evidence for that hardware and environment, not automatic qualification of ours.

*Evidence labels used throughout both companion documents.*

| Label                              | Meaning                                                            | Does not imply                                        |
|------------------------------------|--------------------------------------------------------------------|-------------------------------------------------------|
| Measured or manufacturer-specified | Published device, scene or calibration under stated conditions     | The proposed complete instrument has that performance |
| Executed conditional model         | Retained code/data, run receipt and numerical checks               | Physical validation or a measured scene/population    |
| Method or physical principle       | Derivation, conservation law or documented inference procedure     | Missing parameters are known                          |
| Missing mission evidence           | Selected receiver, source, background or exposure still needs data | The physics question has no useful answer             |

# The 22 original questions

## Initial question - Transmission to nadir at 550 km versus overhead cloud optical depth; cloud-top/above-top source; Rayleigh versus particles.

The fraction is not determined by source altitude and overhead cloud optical depth alone. Specify whether the denominator is all photons emitted, upward escaping photons, photons per unit solid angle toward nadir, or photons incident on an aperture. For an isotropic point source and a small on-axis aperture, the direct vacuum fraction is  $A/(4 \pi R^2)$ . Multiply this direct term by  $\exp[-\tau_{\text{cloud}} - \tau_{\text{gas}} - \tau_{\text{aerosol}}]$  along the source-observer ray. The total, including redirected light, requires a time-dependent angular transport calculation. Scattering removes photons from a ray but does not necessarily destroy them.

At 337.1 nm the reviewed dry US Standard Atmosphere calculation gives vertical Rayleigh optical depth about 0.0888 at 15 km, 0.0759 at 16 km and 0.0555 at 18 km. Direct molecular transmissions are about 0.915, 0.927 and 0.946. The older CloudScat exponential 7.2 km atmosphere gives 0.921, 0.931 and 0.947 respectively. Thus Rayleigh is a several-percent direct-beam effect even above the source; the pressure/profile approximation is a smaller but recorded systematic. These factors exclude ozone, aerosols and diffuse photons scattered back into acceptance.

Cloud particles usually dominate scattering inside an optically substantial anvil. At the cloud top the overhead particle optical depth can vanish while molecules remain. An above-top source also illuminates the cloud beneath it: reflected photons can add a delayed component in the upward viewing direction. A directional increase relative to a no-cloud view is consistent with energy conservation. It must not be described as cloud transmission greater than the fraction of emitted photons.

Use  $\beta_{\text{ext}}$ , single-scattering albedo and the angular phase function or matrix, together with physical cloud dimensions, source position and emission pattern. Identical optical depth with different physical distance or phase shape need not give the same delay. Ice crystals near anvil top are often nonspherical; Mie theory is exact for a homogeneous sphere, not for every ice habit. Ozone absorption and stratospheric aerosol cannot be assumed absent solely because the source is high.

For perspective, an overhead particle optical depth 0.01 is smaller than the reference molecular 0.055-0.089 column above 15-18 km; particle depths 1-10 are much larger. This compares direct-ray extinction only. Different angular scattering and cloud reflection still determine total received light.

**Corrections retained.** Direct-beam extinction is not total detected fluence. Cloud-top does not mean vacuum; above-top does not mean no cloud contribution. The 25 mm aperture used in examples is an illustrative design variable, not an established requirement.

$$K_{\text{direct}} = A \cos(\theta) \exp(-\tau_{\text{LOS}}) / (4 \pi R^2)$$

Fraction of isotropically emitted photons reaching a small planar aperture without collision. Conditions: Point source; small aperture; stated line-of-sight extinction; no focusing or PDE included.

$$\tau = \int \beta_{\text{ext}}(s) ds; E_{\text{ph}} = h c / \lambda$$

Optical depth is dimensionless. Photon energy at 337.1 nm is about  $5.89 \times 10^{-19}$  J. Conditions: Gas, aerosol and particle terms must use the same spectral and geometric conventions.

**Conditional calculation:** Dry reference Rayleigh column and direct transmission; neither real polar weather nor total diffuse transmission.

**Physical model:** Directional multiple scattering depends on phase, geometry and cloud below the source.

**Still needed.** Event-specific cloud geometry, overhead gas/aerosol/ozone columns, source angular emission and absolute photon output. Validated ice phase/absorption properties and actual aperture/field/time acceptance.

Related fresh calculations: R4-N01, R4-N02, R4-N03, R4-N11.

Sources: [S027]; [S032]; [S034]; [S036]; [S037]; [S097]

## A-1 - Which radiative-transfer calculation/tool should be used, and alternatives to CloudScat?

CloudScat.jl remains a practical primary tool because it was developed specifically for internal lightning emission viewed from space, and it has actually been installed and exercised in the earlier project. Its outputs are conditional on the supplied optical properties, geometry and source waveform. A large packet count reduces Monte Carlo sampling error; it does not validate those physical assumptions.

The most promising independent alternative identified in the campaign is MCAR aTS: the retrieved 0.10.3 source contains direct-source local estimates and path-length histograms. Its source and interfaces were inspected, but no compiler/dependency build or matched 337 nm execution was completed in that campaign. An isotropic source cannot be represented by an invalid 360 degree full-cone parameter if the code only permits 180 degrees; two opposite half-power hemispheres are one possible valid construction.

Other relevant tools solve different parts of the problem. SMART-G and nonspherical-ice lookup tables can provide realistic steady radiative transfer and particle properties. Public libRadtran includes a restricted subset of MYSTIC functionality; access to the required 3D version must be verified. MSCART/McRALI and published transport models provide useful comparisons, while general transient renderers such as mitransient require careful unit, source, phase and optical-path audits. ARTDECO is useful for atmospheric optical properties and steady calculations, not automatically a drop-in transient lightning solver.

The fresh revision calculation, if its execution receipt is present in the numerical appendix, is an independently written idealized Num Py transport diagnostic. It is not an independent real-ice validation or a replacement for a qualified production code. Before comparing models, match source normalization, boundaries, detector geometry, direct light, time origin and phase convention. Benchmark vacuum, Beer-Lambert direct light, isotropic single scattering, energy balance and convergence before interpreting cloud-depth curves.

The fresh independent cylinder implementation now has two executed matched ideal HG cross-code controls against CloudScat, with fluence differences 0.41 and 0.69 combined estimated SE. This is a limited new implementation result. It does not validate tabulated GHM, realice, timinganalysis or source-depth inversion.

**Corrections retained.** Available documentation, downloaded code, an installed executable and a validated calculation are different states. Do not advertise all named atmospheric tools as equivalent transient 3D solvers.

$$y(t) = \text{integral } s(t-u) K(u; \text{geometry, optics}) du$$

Separate source emission history  $s$  from the propagation impulse response  $K$ . Conditions: Linear transport and fixed medium; detector response is a further convolution.

**Published model and prior execution:** CloudScat geometry-specific methods and earlier project execution.

**Source interface audit:** Alternative interfaces were inspected with explicit build/access limits.

**Still needed.** A matched independent transient benchmark using the same real-ice properties and detector estimator. A validated event-specific source/cloud model.

Related fresh calculations: R4-N11.

Sources: [S028]; [S029]; [S030]; [S031]; [S033]; [S038]; [S097]

## A-2 - Multiple scattering and temporal profile; robustness of 30-80 us versus >200 us rise-time discrimination.

Multiple scattering can lengthen the optical path and produce a delayed rise and tail. It can therefore carry information about source depth. It does not supply a universal one-to-one map from rise time to depth. Physical depth, extinction, angular scattering, cloud boundaries and the intrinsic emission history all enter the observed waveform.

The proposed 30-80 microsecond versus greater-than 200 microsecond separation is a hypothesis to validate, not a demonstrated classifier at 550 km. The literature uses different rise definitions, including onset-to-peak and 10-90% amplitude. They cannot be interchanged. The measured signal is the source history convolved with cloud transport, detector/electronics response and sampling/integration. A source can keep exciting nitrogen after its earliest light; a long tail need not be solely propagation.

The universal greater-than 3 ms source duration is also unsupported: published shallow blue-flash examples include 200-910 microsecond durations, and multipulse events can contain renewed source activity. Nitrogen excited-state lifetimes and collisional quenching are fast, while continuous/repeated excitation can make a longer optical event. A fit assuming an instantaneous source does not independently prove that assumption.

At 10 kS/s the 100 microsecond sample spacing under-resolves a 30-80 microsecond edge. At 50 kS/s, 20 microsecond spacing gives only 1.5-4 samples. Model fitting can extract information between samples only with a valid pulse/noise/phase model. At 50 kS/s the Nyquist frequency is 25 kHz; an analogue 50 kHz bandwidth cannot be treated as unaliased baseband. Photon arrivals on the leading edge, not merely total event photons, determine timing information. Dead time and saturation can also make an observed rise artificially short.

The fresh 81,000 trial receiver-morphology study makes the detect-versus-classify distinction concrete. With 50 kS/s, background 50/s and 100 plateau-equivalent PE, true 30 us pulses were detected in 1000/1000 trials, but only 21 were accepted by the declared fast/slow score-margin rule. With zero errors among those 21, the upper endpoint of an individual two-sided exact 95% error interval is still about 16.1%. With 1000 scale PE, the accepted fractions improve but remain source-shape/background dependent. These are synthetic receiver-input shapes, not independent cloud-depth labels.

**Corrections retained.** Keep intrinsic, cloud-propagated and sampled rise times separate. Keep onset-to-peak and 10-90% definitions separate. A tail or a fast leading edge alone does not uniquely identify depth or discharge class.

$$y = \text{sample}\{s * K_{\text{cloud}} * h_{\text{receiver}}\} + \text{noise}$$

The star denotes convolution; every stage can alter timing. Conditions: Linear response before any explicitly modeled dead time or saturation.

$$\text{delta}_t = (L_{\text{path}} - R_{\text{straight}}) / c$$

Extra path length gives propagation delay relative to the direct ray. Conditions: Bulk transport at approximately vacuum light speed; source-to-observer flight time is not rise time.

**Measured examples and model assumptions:** Published source durations and fitted propagation examples have distinct definitions and selection.

**Conditional method:** Sampling and dead-time diagnostics demonstrate potential estimator biases, not mission confusion rates.

**Still needed.** Consistent rise definitions and independently labeled source depths/classes. Intrinsic pulse families, realistic cloud phases/geometry and calibrated receiver response/noise. Injection-recovery over actual leading-edge counts, background, sample phase and count losses.

Related fresh calculations: R4-N02, R4-N03, R4-N04, R4-N09, R4-N11, R4-N12.

Sources: [S035]; [S066]; [S067]; [S079]; [S099]; [S100]; [S106]; [S107]

## B-4 - Absolute nightside 337 nm radiance: quiet airglow, moon, zodiacal light and integrated starlight.

No single verified polar, cloud-viewing 337 nm background radiance was established. The needed quantity is a spectral and angular scene radiance folded with the actual receiver response. Quiet airglow, aurora, reflected moonlight, zodiacal illumination and direct/diffuse starlight have different geometries and cannot be replaced by one broadband number divided by a chosen width.

A useful bounded example is the published Noll et al.(2024) mean pseudo-continuum derived from 10, 633 selected Paranal spectra. Folding that table with a unit top-hat 335.1-339.1 nm band gives about 7.08e-9 W m<sup>-2</sup> sr<sup>-1</sup> integrated, or 1.77e-9 W m<sup>-2</sup> sr<sup>-1</sup> nm<sup>-1</sup> averaged over 4 nm. This is a processed low-latitude ground reference: strong resolved lines and modeled extraterrestrial components were removed, observations are long integrations, and extinction/layer geometry were corrected. It is not total sky, a quiet polar distribution or a satellite-cloud measurement.

The Bianchi(2024) direct-plus-diffuse starlight cube gives about 8.23e-10 W m<sup>-2</sup> sr<sup>-1</sup> nm<sup>-1</sup> as an all-sky mean interpolated near 337.1 nm. Its roughly 13 nm spectral bracketing is too coarse to certify a 4 nm stellar spectrum. An Earth-filled nadir instrument generally receives this component after atmospheric/cloud reflection, not as a direct celestial view. The campaign evaluated hypothetical cloud-normal hemispheres, not mission orbit/date illumination.

Public RAIDS near-UV spectra were decoded and their count/calibration relation checked privately. Their limb geometry, sequential wavelength scan, preflight calibration, additive backgrounds and publication terms prevent treating selected rows as clean 4 nm nadir radiance. TEMPO and Mini-EUSO give additional measured context, but their processing, broad responses and viewing geometry differ. These are constraints and research routes, not interchangeable background measurements.

**Corrections retained.** Noll pseudo-continuum is not total night sky. Broad UV orbital counts are not a measured 4 nm 337 nm polar radiance. Limb spectra and cloud-reflected nadir brightness require different transfer.

$$b = \text{integral } A_{\text{eff}}(\lambda, \Omega) L_{\lambda}(\Omega) \lambda / (h c) d\lambda d\Omega$$

Background detected photon rate is a spectral-angular integral. Conditions:  $A_{\text{eff}}$  includes projected collecting area, optical throughput and photon detection probability exactly once.

$$1 R = 10^{10} / (4 \pi) \text{ photons m}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$$

Rayleigh is an emission radiance unit, unrelated to Rayleigh scattering as a mechanism. Conditions: For a spectral value, retain whether it is perm or per Angstrom.

**Published processed measurement:** Noll mean continuum table can be folded conditionally; its selection/subtractions limit mission transfer.

**Published sky model:** Bianchi actual cube provides direct/diffuse stellar angular illumination at coarse spectral resolution.

**Access and geometry qualification:** RAIDS/TEMPO/broad UV results cannot be used as clean target-scene radiance without additional processing.

**Still needed.** A total 337 nm scene distribution with measured components and geometry at high latitudes. Actual filter/field response, cloud directional reflection and gas transmission.

Related fresh calculations: R4-N07.

Sources: [S006]; [S011]; [S012]; [S013]; [S017]; [S018]; [S023]

## B-5 - Auroral 337 nm 4 nm-band brightness and shot-noise floor during moderate/disturbed conditions.

Auroral nitrogen emission falls in the same 337 nm band as the target, so a filter cannot remove it selectively. It raises photon shot noise and may add structured temporal variations. High-latitude operation makes this an important scenario, but no defensible universal conversion from moderate/disturbed Kp to 4 nm nadir radiance was established.

A selected historical spectrum reports a 337 nm band area 2270 +/-290 R with an additional 25% calibration-scale uncertainty. Nearby readings from another historical photometer were about 596-696 R. These differ in observable, weighting, field and calibration; no authoritative correction or universal auroral range was derived. The numbers are selected examples, not a distribution or a statement that every 4 nm filter captures the full reported band area. The numerical appendix may use imposed received radiances to show shot-noise consequences, while labeling them as scenarios.

GLOW contains useful 337/777 emission outputs, with brightness depending on imposed precipitating-particle spectra and flux, atmosphere and viewing geometry. TRE x-ATM's paper-level wavelength capability and the current public API fields must be distinguished: the inspected API did not expose arbitrary 337/777 outputs. OVATION flux/power categories may supply conditional precipitation inputs; they are not optical radiance measurements. Proton/hydrogen excitation and secondary electrons can also matter.

Aurora should not be assumed perfectly constant on every relevant timescale. Primary observations demonstrate subsecond structure and flickering. They do not establish a 337 nm microsecond noise spectrum for this wide field. Even a perfectly steady mean leaves Poisson shot noise; baseline subtraction removes its mean, not that random variance. Geomagnetic classification alone does not specify arc filling fraction, latitude/local time, cloud reflection or the receiver's background.

**Corrections retained.** Same-wavelength auroral photons cannot be filtered away from the target. Slow mean variability does not eliminate shot noise, and aurora is not universally slow. An imposed precipitation/model case is not a measured Kp-conditioned sky distribution.

$$\text{Var}(N_{\text{background}}) = b T$$

Ideal Poisson background counts have variance equal to their mean. Conditions: Independent arrivals, known live time and no correlated detector noise; estimating the baseline adds variance.

$$L_{\text{band}} = R_{\text{band}} [10^{10}/(4 \pi)] h c / \lambda$$

At 337.1 nm, 1 R corresponds to about  $4.69 \times 10^{-10} \text{ W m}^{-2} \text{ sr}^{-1}$  integrated. Conditions: Band-integrated Rayleigh, not R per nm; source spectral capture must be specified.

**Selected measurement:** Historical band-area and photometer intensities are examples with material observable/calibration differences.

**Model and interface audit:** GLOW and precipitation tools support conditional forward calculations; current API capability and optical validation remain limited.

**Measured temporal structure:** High-speed auroral observations reject a universal seconds-to-minutes-only assumption.

**Still needed.** A calibrated 4 nm 337 nm radiance/time distribution for the actual high-latitude field and scene. Precipitation spectra, arc filling, cloud transfer and actual detector end-of-life noise.

Related fresh calculations: R4-N05.

Sources: [S001]; [S007]; [S008]; [S009]; [S024]; [S025]; [S026]

## B-6 - Lunar phase/elevation at which cloud background dominates detector noise.

There is no universal lunar phase or elevation at which photon background overtakes detector noise. The crossover depends on aperture, field, filter equivalent bandwidth, optical response, detector temperature/dark statistics and estimator duration. Moon elevation at the cloud and lunar phase/libration affect incident irradiance; cloud reflectance and atmospheric paths determine what reaches the satellite.

For a Lambertian example  $L_{\lambda} = \rho E_{\text{Moon}, \lambda} \cos(z_{\text{Moon}})/\pi$ , with transmission factors and a real directional reflectance model added as needed. This is a conditional scene model, not a measured anvil BRDF or universal lunar spectrum. A useful crossover compares variance after the same estimator: background photon variance against dark/electronic/correlated variance, not mean optical power against amplifier current without conversion.

The calibration literature has important wavelength limits. ROLO's fitted observations begin around 350 nm. Air-LUSI measured 350-980 nm and demonstrated its strongest stated  $\leq 1\%$  result over 450-970 nm, not 337 nm. LIME's actual available observed bands do not establish a 337 nm absolute reference merely because a broader model description is given. A proposed 320 nm-capable LUSI system is not a demonstrated 0.5% 337 nm lunar standard. GOME/LROC and LESSR offer UV routes but require actual wavelength, phase, absolute-scale and data-access qualification.

The current design should therefore carry lunar scenarios with explicit uncertain 337 nm irradiance and cloud transfer, and report a crossover in received radiance/count rate. Convert that into phase/elevation only after choosing and validating a UV lunar model and receiver. Cloud, Moon and orbital night selection are correlated; multiplying independent marginal duty-cycle fractions is generally unjustified.

**Corrections retained.** Do not transfer visible-band lunar absolute accuracy to 337 nm. Background-limited is a comparison of noise variances for a specified receiver and estimator.

$$L_{\text{Moon}, \lambda} = \rho E_{\text{Moon}, \lambda} \cos(z_{\text{Moon}}) / \pi$$

Ideal Lambertian reflected spectral radiance. Conditions: Homogeneous diffuse reflector; specified albedo and transmission, no claim of anvil angular behavior.

$$\text{background limited when } V_b > V_{\text{detector}}$$

Compare variance after the same integration/filter/estimator. Conditions: Include baseline-estimation covariance and detector correlations.

**Published calibration with wavelength limits:** ROLO, LIME and air-LUSI references have specific demonstrated bands and geometry.

**Conditional model route:** UV lunar/solar routes require additional coefficients, access and validation.

**Still needed.** Validated 337 nm lunar irradiance versus phase/libration and cloud illumination geometry. Chosen receiver noise/temperature, spectral-angular response and cloud reflection.

Related fresh calculations: R4-N05.

Sources: [S002]; [S003]; [S004]; [S005]; [S010]; [S014]; [S015]; [S016]

## C-7 - Detector choice at 337 nm, large area and 10-50 kHz; claimed photodiode/TIA floor.

The proposed silicon-photodiode exclusion is not a universal law. Transimpedance gain, amplifier open-loop gain, detector/input capacitance, feedback compensation and multiple gain stages determine bandwidth and stability. A quoted product for one module cannot set a physical ceiling for every architecture. A 2026 bench study reports 1 Gohm total gain with 30 kHz output filtering and 3.898 pA RMS open/shielded-input noise; this refutes a universal 1 nA floor but does not establish our detector-coupled 337 nm sensitivity or flight suitability.

A PMT offers large receiving area and internal multiplication with low electronic readout burden; its costs include HV, magnetic sensitivity, bright-light protection, gain/collection calibration and count/charge dynamic range. SiPMs offer solid-state gain and modular area, but dark counts, capacitance, optical crosstalk, afterpulsing, recovery and radiation damage grow important as area increases. Linear APDs provide gain without Geiger holdoff but require excess-noise, capacitance, bias/temperature and amplifier treatment. PIN and UV-selective SiC photodiodes remain candidates to evaluate, not devices already shown adequate.

A back-illuminated CMOS camera has many pixels. Its per-pixel read noise and short minimum exposure do not mean the whole active area can be summed at 50 kHz with the same noise. An inspected GSENSE400BSI specification gives 48 full frames/s, 1.6 electrons typical temporal noise per pixel and peak QE at 570 nm. Neither exact 337 nm QE nor fast full-area flight operation follows. ROI readout changes area/field unless the optics are redesigned.

Choose the detector together with the optics, background, required timing and gain range. For example, a 6 x 6 mm SiPM may have high PDE but cannot receive every ray from a 25 mm aperture over a 60-90 degree cone in air without collection loss. A small red APD has the same geometric issue. The preferred baseline is therefore a flight-like PMT counting/analogue comparison with at least one specified semiconductor chain, followed by equal aperture-photon injection tests; it is not a class-wide hardware purchase decision.

**Corrections retained.** A vendor gain-bandwidth product is not a universal detector limit. Peak QE at 405, 450 or 570 nm is not measured 337 nm response. Per-pixel noise and minimum exposure do not specify a 50 kHz large-area photometer.

$$V_{\text{out}}(f) = Z_T(f) I_{\text{photo}}(f)$$

Transimpedance is a frequency-dependent circuit response, not merely a gain number. Conditions: Actual capacitance, stability, layout and feedback must be retained.

**Bench measurement:** A published high-gain TIA counterexample rejects the universal floor without qualifying this receiver.

**Manufacturer specification:** Exact detector area, capacitance, wavelength and readout conditions restrict technology comparisons.

**Prototype measurement:** SiSMUV 405 nm response and planned radiation tests do not establish a 337 nm flight receiver.

**Still needed.** Selected sensor/package 337 nm PDE or responsivity, actual sensitive area/capacitance and bias/temperature-dependent dark PSD or correlated-count distribution Complete readout noise, impulse response, power and permitted readout mode; for CMOS, measured full accepted-area cadence and summed read noise, not minimum exposure alone

**Next inputs/tests.** Required aperture/field, temperature, sample rate in S/s, analog bandwidth and estimator ENBW as separate quantities

Related fresh calculations: R4-N08, R4-N12.

Sources: [S055]; [S057]; [S058]; [S059]; [S061]; [S069]; [S085]

## C-8 - NEP and aperture photons per event for candidate detectors.

NEP is input optical power that produces signal comparable to noise under a stated convention. A spectral NEP in W/sqrt(Hz) is not a bandwidth-integrated power, event energy or photon threshold. A spot value at 1 kHz cannot be multiplied blindly by sqrt(50000) when the noise spectrum, analogue filter and estimator weighting are not flat. Count-mode detectors may be better described by DCR, PDE, correlated-count statistics and a likelihood.

Use measured input-current PSD divided by actual spectral responsivity for a linear chain, then integrate through the transfer function. For APDs, distinguish unmultiplied surface leakage from multiplied bulk current: the Hamamatsu technical model gives  $2 q[(I_L + I_{dg})M^2 F + I_{ds}]B$ . Multiplying an already multiplied catalogue total current by  $M^2$  can double-count gain. SiPM crosstalk/afterpulses and PMT multiplication variance require their own treatment.

The fresh design appendix gives dark-only examples using explicitly assumed dark-count, photon-efficiency and excess-noise scenarios. They exclude amplifier and optical background and are not promised operating NEPs. Likewise the preliminary SUR500x table gives 18 fW/sqrt(Hz) at 350 nm, gain M=100, not a qualified 337 nm receiver value. The actual temperature and noise-frequency conditions must be supplied before using it for a flight requirement.

Translate a validated detected-signal requirement S into aperture photons with  $N_{ap}=S/\eta$  only when  $\eta$  is the appropriate spectral/angle/time-weighted efficiency. Fluence is  $N_{ap}/A$  for uniform illumination. Detection probability and false-alarm control determine S; a generic 5 sigma rule can be wrong at low counts or after searching billions of windows. A pulse with many total counts may still lack enough leading-edge counts to estimate its rise. No single NEP table by detector class can answer that combined detection-and-timing question.

For the fresh linear-ramp morphology example, 100 plateau-equivalent PE across 3 ms with a 30 us 10-90 rise means 99.375 actual expected source PE but only 0.4 expected source photoelectrons in the first 30 us. An integrated detection can therefore be secure while rise estimation remains weak.

**Corrections retained.** Separate spot noise density, integrated RMS, dark current, DCR and detection probability. Do not apply photocathode gain or APD multiplication twice. Aperture photons and registered counts use different reference planes.

$$\sigma_{P^2} = \int NEP(f)^2 |H_{est}(f)|^2 df$$

Input-equivalent power variance for a specified linear estimator. Conditions: Consistent one-sided PSD convention and responsivity; include correlated terms as needed.

$$N_{ap} = S_{required} / \eta; \Phi_{ph} = N_{ap} / A$$

Convert detected signal to incident photons and photon fluence. Conditions: Efficiency must match source spectrum, field, timing and live time.

**Device noise model:** APD surface/bulk noise and multiplication require the correct current convention.

**Manufacturer specification with limits:** Published noise/area/PDE figures are part-specific, not class guarantees.

**Method:** The estimator and analogue/ADC filtering define integrated noise.

**Still needed.** Actual receiver spectral noise/count statistics, gain/excess noise and target-band throughput at beginning/end of life Injection-recovery versus aperture photon fluence under relevant backgrounds, integration windows, pulse shapes and false-trigger rules

**Next inputs/tests.** Reference plane for photons, spectral versus integrated NEP, filter/estimator transfer and correlated-noise treatment

Related fresh calculations: R4-N05, R4-N08, R4-N09, R4-N10.

Sources: [S057]; [S060]; [S062]; [S065]; [S070]; [S094]

## C-9 - DC coupling and preservation of a>3 ms pulse.

DC coupling is feasible and does not require a new physical detector principle. A PMT with negative cathode HV and its anode at ground can drive a DC-coupled analogue current/voltage chain. ET Enterprises explicitly describes this topology; the named HV 2520 CN base supports AC or DC output coupling. These are commercial architecture facts, not measured flight noise or external-vacuum qualification.

AC coupling has two distinct meanings. If a capacitor high-pass-filters the millisecond analogue optical envelope, a flat pulse droops and the falling edge produces a baseline excursion. For an ideal single-pole high-pass, less-than 5% droop over 3 ms requires  $\tau > 58.5$  ms, or cutoff below 2.72 Hz. Real multi-stage responses require measurement. A short coupling constant can bias amplitude and an onset/threshold estimator even when the initial sharp edge remains.

In a photon-counting PMT architecture, each detected photon produces a nanosecond electrical pulse. That individual pulse may be AC shaped and discriminated; accumulating its occurrences in 10 microsecond bins can preserve a millisecond photon-arrival-rate envelope. The key limitations then are threshold/gain stability, baseline movement, pile-up, dead time and overload recovery, not the high-pass time constant applied to the optical envelope.

MMIA demonstrates such counting heritage but not unlimited linear rate. At bright-end rates a mean dead-time correction becomes uncertain and does not recreate lost arrival times or a Poisson process. Test faint-to-bright sequences, >3 ms plateaus and 30 microsecond edges through the actual chain at random sample phase and

temperature. Any design needing simultaneous faint and very bright events may require parallel gains, attenuation or a dedicated analogue path.

**Corrections retained.** Envelope AC coupling and per-photon pulse shaping are different operations. DC feasibility does not certify complete-chain noise, stability or vacuum compatibility.

$$\text{plateau}(t)/\text{plateau}(0) = \exp(-t/\tau_{\text{HP}})$$

Ideal high-pass step-response droop. Conditions: Single-pole analogue envelope model; not a photon-counter count-rate response.

$$m = r/(1+r \tau_d)$$

A nonparalyzable counter mean-response example. Conditions: Stationary/quasistatic Poisson arrivals and known fixed dead time; not an exact noisy-waveform correction.

**Manufacturer architecture:** Grounded-anode negative-HV coupling and named AC/DC base are documented.

**Flight architecture:** MMIA counts fast PMT pulses into 10 microsecond bins.

**Measured failure context:** Real receiver transient and saturation effects need device-specific tests.

**Still needed.** Full-chain optical impulse/step and >3 ms pulse response across faint/background/overload conditions Droop, pedestal, saturation, recovery, discrimination/dead time and pulse-phase bias with actual ADC integration/filtering

**Next inputs/tests.** DC analog envelope versus AC-shaped individual-photon counting architecture and exact coupling schematic

Related fresh calculations: R4-N04, R4-N08, R4-N12.

Sources: [S063]; [S064]; [S066]; [S079]; [S088]

## C-10 - 2-3 year 550 km polar/SAA radiation effects on dark current and gain.

A reliable 2-3 year forecast at 550 km polar inclination requires the chosen orbit epoch, shielding CAD, temperatures, bias states and detector lot. Total ionizing dose, displacement damage, single-event upsets/latch-up, prompt charged-particle pulses and cumulative optical/gain aging are separate mechanisms. On/off operation may affect some bias-related damage but does not block penetrating displacement damage.

Measured heritage is informative but cannot supply a universal ranking. GRID-02 reports 93-110 microampere/year dark-current growth per 6 x 6 mm SiPM at 5 C in a 457 x 467 km orbit. Spoo Qy-1 follows specific SAP500 APDs and custom quenching for 600 days while altitude fell 418 to 378 km at 51.6 degrees. Its count growth, geometry and temperature are not a 550 km polar coefficient. CMOS radiation tests show hot/noisy pixels and random-telegraph tails; long-exposure test structures do not determine 20 microsecond full-camera noise.

Proton-tested APDs can retain timing/PDE while dark counts grow severely; cooling and annealing may help dark counts but can alter afterpulsing or exceed a safe thermal/power budget. In one passive-quench bench experiment, extreme activity caused over-saturation: registered counts fell while true activity increased. PMTs avoid the same silicon bulk-dark-current mechanism but still have HV electronics, window/cathode/MCP aging, magnetic response and prompt particle/light artifacts. Small PMT sample studies do not establish a class-wide radiation winner.

Prompt false events deserve their own budget. TUS observed fast track-like flashes in UV channels, with simulations implicating filter interactions and an anti-trigger reducing that class. Ice Cube measured correlated millisecond internal-light bursts in a very different glass/gel assembly. These examples do not predict this instrument's rate, but show why a UV-only event or millisecond duration is not a universal astrophysical veto. Test the actual head, filters and electronics for particle signatures, correlated noise, saturation and recovery.

**Corrections retained.** Operational lifetime is not preserved faint-photon sensitivity. Prompt hits are distinct from cumulative radiation degradation. Cooling, annealing and detector-class ranking remain device/circuit/mission specific.

$$\text{end-of-life response} = \text{function}(\text{part, lot, fluence spectrum, dose, shielding, bias, temperature, history})$$

No single dose-to-DCR factor spans all technologies. Conditions: Use radiation transport and measured component response, with uncertainty.

**Flight measurement:** GRID and Spoo Qy degradation data have explicit device, temperature, orbit and readout conditions.

**Bench irradiation:** APD/CMOS damage and mitigation show mode-specific limitations.

**Measured artifact examples:** Particle/filter and correlated internal-light events motivate controls, not transferable rates.

**Still needed.** Selected device/lot pre/post proton, TID and SEE tests at intended temperatures, including PDE/gain, noise PSD/DCR, correlated noise and annealing limits Prompt particle/window/coating/electronic pulse shapes and false-event/veto response of the

assembled head

**Next inputs/tests.** Orbit epoch/inclination/altitude history and shielding CAD/materials; thermal/power and bias/protection states

Sources: [S077]; [S078]; [S079]; [S080]; [S081]; [S082]; [S083]; [S084]

## C-11 - European suppliers for flight or near-flight detectors.

ET Enterprises is a reasonable first supplier to evaluate for closest MMIA blue-photometer heritage; Photek is credible for custom MCP/intensified space assemblies. This is a shortlist to investigate, not a declaration that either offers a catalogue receiver qualified for this mission. Manufacturing country, corporate/sales location, delivered qualification and exact wavelength performance are separate procurement attributes.

ET9111B/WB bialkali and 9113B/WB S20 families have documented 22 mm active diameter in 25 mm-class outer tubes. Their M selection offers supplied spectral-response calibration; flying-lead and custom-selection options exist. Neither the peak QE nor a typical curve guarantees exact 337.1/777.4 nm PDE. MMIA's paper names the supplier but not the catalogue model, so these families must not be labeled the actual flight tube. Manufacturer reduced-pressure cap precautions do not qualify the complete HV base/module.

The independent UVIT flight paper identifies Photek UK custom intensified CMOS detectors, including an S20/silica VIS channel covering 320-550 nm, with assembled-payload thermal-vacuum/vibration tests and in-orbit images. This does not transfer its qualification to all current MCP-PMT configurations or establish exact 337 nm efficiency, 777 nm response or 50 kS/s operation.

First Sensor's inspected ESCC certificate 379 A covers ATH assembly/test processes for hermetic n-channel power MOSFETs; it is not APD optical-product approval. Its commercial red-sensitive APD arrays remain candidates requiring their own evidence. Laser Components' preliminary SUR 500 x UV APD is a small-area candidate, while the independent SAP 500 flight study concerns another family/custom circuit. The company identifies APD manufacturing in Arizona. Excelitas identifies a Canadian sensor facility; European sales access alone is not European manufacture. No complete off-the-shelf European-manufactured 337/777 receiver with the required full qualification was verified in the bounded search; this is not proof of market absence.

**Corrections retained.** Do not identify ET catalogue candidates as the unpublished MMIA model. First Sensor MOSFET process approval is not APD certification. Hermetic packaging, supplier heritage and European sales presence are not complete flight qualification or lot origin.

**Manufacturer options:** ET exact families, calibrated selections and base/vacuum guidance are documented.

**Independent flight assembly:** Photek custom UVIT heritage has an independent paper.

**Formal scope and manufacturing:** ESA certificate scope and actual global manufacturing statements limit supplier inferences.

**Still needed.** Part/lot-specific spectral calibration at 337/777 and accepted qualification/acceptance results for the actual detector, base, HV and readout build

**Next inputs/tests.** Manufacturer/wafer/assembly country-of-origin declaration if European manufacture is required; screening/traceability and complete external-vacuum/materials/HV qualification scope

Sources: [S086]; [S087]; [S088]; [S089]; [S090]; [S091]; [S092]; [S093]; [S094]; [S095]; [S096]

## D-12 - Maximise nonimaging photometer etendue within roughly 1U.

Maximize useful accepted phase space, not aperture diameter alone. For a circular cone in air,  $G = A \pi \sin^2(\theta_{\text{half}})$ . An ideal lossless concentrator into a flat detector accepting a hemisphere has  $A_{\text{detector}} \geq A_{\text{entrance}} \sin^2(\theta_{\text{half}})$ . A 25 mm circular entrance therefore requires at least 122.7 mm<sup>2</sup> detector area for 60 degree full field or 245.4 mm<sup>2</sup> for 90 degrees. These are necessary bounds, not a realizable design or guarantees against aberration, vignetting and losses.

A small high-PDE SPAD or 0.5 mm APD cannot accept that entire 25 mm/wide-field input through air. A mosaic can provide more area, but brings summed dark/electronic/correlated noise, dead space and readout power. Immersion can change the refractive-index factor only with a specified physical coupling; inserting silicon's bulk index for an air-gapped package is invalid.

MMIA's custom relay combines a nominal 1 mm UV entrance with a 25 mm photocathode. Its 337/777 field is an 80 degree square diagonal; circular-cone bounds cannot be applied without integrating that field. The reviewed square-field phase-space integral is 0.9631 sr of projected solid angle. A 25 mm entrance with every ray at one flat

filter constrained within 10 degrees requires at least 79.71 mm circular clear filter in the ideal air/lossless model. Space for lenses, baffles, detector, HV, thermal paths and electronics is additional.

A reflective collector avoids chromatic lens absorption but still faces obscuration, coating, field and concentration constraints. A nonimaging concentrator can be efficient within a defined angular acceptance; a bare detector plus baffle is simple but sacrifices aperture or field/stray rejection. None was proven best within 1U. A ray-traced packaged layout and measured acceptance are required. Enlarging aperture raises both source and diffuse-background counts; in a background-limited fixed-field limit, signal-to-noise grows with diameter, not area.

**Corrections retained.** The 25 mm MMIA photocathode is not its UV collecting aperture. Conservation of etendue cannot be bypassed by nonimaging optics or high PDE. Circular 60/90 degree and square 80 degree-diagonal fields require different integrals.

$$G = n^2 \int_A \int_{\Omega} \cos(\theta) d\Omega dA$$

Optical etendue is conserved by ideal passive lossless optics. Conditions: Actual refractive coupling and field/pupil acceptance must be specified.

$$A_{\text{det}} \geq A_{\text{ent}} \sin^2(\theta_{\text{half}}) \text{ (air-to-air)}$$

Ideal concentration into a detector hemisphere. Conditions: Circular cone, flat projected areas; losses and package restrictions can only reduce acceptance.

**Optical principle:** Etendue gives necessary collection-area/angular bounds.

**Flight design:** MMIA/GLIMS optical arrangements supply hardware context, not a 25 mm Cube Sat relay.

**Still needed.** Assembled field/pupil/wavelength response, vignetting, detector illumination uniformity, throughput and baffle/stray-light rejection

**Next inputs/tests.** Ray-traced optical phase space with actual stops, clear areas, refractive coupling, obscuration and detector active area; 1U mass/volume/thermal/power layout

Related fresh calculations: R4-N06, R4-N08.

Sources: [S054]; [S066]; [S073]

## D-13 - Maintain narrowband filter response over 60-90 degree full field.

A thin-film interference filter generally shifts toward shorter wavelengths as incidence increases, with polarization splitting and a finite cone broadening the effective response. The common effective-index formula  $\lambda(\theta) = \lambda_0 \sqrt{1 - \sin^2(\theta)/n_{\text{eff}}^2}$  is a useful limited-angle estimate. It is not a substitute for measured 337 nm coating data over field, pupil, temperature and polarization.

Telecentricity can make chief-ray angles similar across field, but does not remove the marginal-ray cone. Radially graded coatings can compensate a predictable spatial mean angle; they do not automatically undo the range of angles crossing each point. A larger filter/pupil can reduce the angular spread at a cost in size. Widening the band can retain more source light but also admits more background and possible spectral contaminants.

MMIA uses a relay and internal interference filter with telecentric illumination, followed by a square field stop and distribution optics. Its published CAD drawing is not an optical prescription: filter diameter, F-number and actual marginal-ray angles cannot be measured from an unscaled illustration. Fig 6 supplies one curve per channel without a full angle/temperature setup. Section 6.3 explicitly notes an angle correction  $C(\theta)$  but does not provide its map.

For the proposed wide field, compute the entire wavelength-angle response, then fold source and background spectra. The appropriate design choice may be a larger relay, a smaller field, a wider filter, a larger receiving area or another architecture. A nominal 4 nm/80 degree heritage specification does not decide among them. The fresh design appendix's angle/width numbers are idealized sensitivity cases, not an accepted coating design.

**Corrections retained.** Telecentric does not mean every ray is normal to the filter. Do not infer a PHOT cone or filter diameter from the camera F-number or unscaled CAD.

$$\lambda(\theta) / \lambda_0 \approx \sqrt{1 - \sin^2(\theta)/n_{\text{eff}}^2}$$

Approximate interference-filter blue shift. Conditions: Hypothetical effective index unless measured; not valid as a universal high-angle coating model.

**Optical method:** Finite-cone and thermal effects require coating-specific characterization.

**Published hardware scope:** MMIA documents a relay and nominal passband, but no complete off-axis spectral map.

**Still needed.** Filter transmission map versus wavelength, actual ray angle/cone, polarization, temperature and vacuum for the selected coating Full-field assembled spectral response including pupil weighting and tolerances

**Next inputs/tests.** Optical prescription and clear filter diameter; actual ray distribution and any radial grading registration

Related fresh calculations: R4-N08.

Sources: [S066]; [S071]; [S074]

## D-14 - Is 4 nm FWHM optimal for the N2(0, 0)band and background?

Four nanometres is a reasonable heritage starting point, not an established SNR optimum. N2 second-positive(0, 0) emission is a rovibronic band with structured line positions and populations, not a delta function at a single label 337.1 nm. Capture depends on population/temperature assumptions, band-head registration, filter shape and angular/thermal changes. More emitted wavelengths are useful only when the background and competing emissions are also included.

The campaign narrowed public primary line-list/database routes and found material coordinate/population issues. Conditional line reconstructions using lower-state energy/J assumptions were explored but do not establish an NBE rotational/vibrational population or a flight optimum. This revision does not retain an earlier unvalidated molecular-line reconstruction as a validated spectrum. A Gaussian synthetic source in the fresh design algebra is explicitly a hypothetical shape, not a reconstructed N2 band.

For flat background, its variance often grows approximately with equivalent filter width. If all useful source photons are already captured, further widening degrades background-limited SNR approximately as  $1/\sqrt{\text{width}}$ . If a narrow filter loses source photons, widening can instead help. The optimum maximizes the actual detection/timing objective, including filter transmission, PDE, scene spectrum and false alarms. A 4 nm-FWHM Gaussian of unit peak has equivalent width about 4.26 nm, not 4 nm.

Use one air/vacuum convention for source lines, solar/stellar spectra and filter measurements. Around 337 nm the coordinate difference is about 0.1 nm; near 777 nm about 0.21 nm. This coordinate conversion is distinct from a physical coating shift caused by vacuum or temperature. The Noll table wavelength convention is not fully verified at the final processed level, so its narrow folds retain that qualification.

**Corrections retained.** A nominal band-head wavelength is not a complete emission spectrum. FWHM is not equivalent noise bandwidth. Unvalidated line-list reconstruction and assumed NBE temperatures cannot select the flight filter.

$$S(w) = \int \Phi_{\text{source}}(\lambda) T_w(\lambda) \eta(\lambda) d\lambda$$

Detected signal depends on spectral capture, not width alone. Conditions: Also integrate field, pupil and temperature where necessary.

$$\Delta_{\lambda_{\text{eq}}} = \int T(\lambda) d\lambda / T_{\text{peak}}$$

Equivalent width measures accepted smooth-background bandwidth. Conditions: For a unit-peak Gaussian,  $\Delta_{\lambda_{\text{eq}}} = 1.06447$  FWHM.

**Primary spectroscopy and database qualification:** Molecular lines and wavelength conventions require compatible source data and population definitions.

**Spectral response example:** A narrow catalogue filter and Noll continuum folds demonstrate trade-offs without an optimum.

**Still needed.** Representative source-band spectra or validated physical spectral model constrained by source conditions Scene/background spectra and actual assembled filter/detector response with stable wavelength registration

**Next inputs/tests.** Source air/vacuum convention and population/pressure/temperature assumptions; FWHM versus equivalent noise bandwidth; defined detection objective

Related fresh calculations: R4-N07, R4-N08.

Sources: [S013]; [S017]; [S019]; [S020]; [S021]; [S022]; [S072]

## D-15 - Required optical density and rejection wavelength range.

Specify a source-weighted leakage allocation rather than a single unqualified OD number. Compute in-band and out-of-band detected photon rates using the full scene spectrum, filter transmission and detector response. A detector still sensitive in the visible/NIR can receive substantial leakage from red nightglow, moonlight, twilight or bright lightning even when the 337 nm band is narrow.

The inspected Alluxa 337 nm example gives OD 6 over 291-331 nm and 343-380 nm on its listed specification. That does not demonstrate OD 6 from the UV through silicon's near-IR cutoff. A data-sheet plot with limited axes also cannot supply a guaranteed floor below the plot dynamic range. Real blocking depends on angle, polarization, temperature, manufacturing defects, pinholes and aging.

If a uniform out-of-band transmission  $t_{\text{leak}}=10^{-\text{OD}}$  is an explicit assumption and  $C_{\text{out}}$  is the unblocked out-of-band detected rate, requiring leakage below fraction  $f$  of in-band rate  $C_{\text{in}}$  gives  $\text{OD} \geq \log_{10}[C_{\text{out}}/(f C_{\text{in}})]$ . This algebra becomes a useful numerical requirement only after  $C_{\text{out}}$ ,  $C_{\text{in}}$  and the guaranteed wavelength range are known. Spectrally structured leaks require integration rather than one effective OD.

Test the combined filter stack with sufficient dynamic range to support the required rejection, including fluorescence/scintillation and scattered-light paths. A blue-only artifact generated within a window or detector can bypass an external spectral rejection argument. The fresh OD scenarios show conditional allocations, not supplier acceptance or complete mission spectra.

**Corrections retained.** Limited-interval OD 6 is not broadband OD 6. A display plot or unverified average blocking claim is not an acceptance measurement.

$$C_{\text{leak}} = \int_{\text{out}} L_{\lambda} A_{\text{eff, unblocked}} T_{\text{leak}} \lambda / (h c) d\lambda d\Omega$$

Leakage is a detector-weighted integral. Conditions: Scene spectrum and angular/coating response must be specified.

$$\text{OD} \geq \log_{10}[C_{\text{out}}/(f C_{\text{in}})]$$

Uniform-leak allocation example. Conditions: Constant leakage over a stated interval; required fraction  $f$  is a design choice.

**Manufacturer specification:** Exact filter guaranteed intervals limit a quoted OD.

**Published instrument caution:** Optical angle/continuum/blocking assumptions must be retained in ratio systems.

**Scene spectral context:** Solar, nightglow and other-lightning spectra constrain leakage domains with specific wavelength limits.

**Still needed.** Dynamic-range-qualified leak/blocking scan through detector cutoff, including pinholes, angle/polarization/thermal changes and induced fluorescence. Scene spectra sufficient to bound out-of-band photoelectrons and stray light under permitted night/Moon/twilight conditions.

**Next inputs/tests.** Allowed leakage fraction/noise allocation and guaranteed wavelength interval for each coating/blocker.

Related fresh calculations: R4-N08.

Sources: [S013]; [S014]; [S072]; [S076]; [S078]; [S105]

## E-16 - 777.4 nm null-channel detector and comparable photon thresholds.

A silicon APD is a plausible red-channel option, not a forced solution. GaAs photocathode PMTs can outperform ordinary multialkali QE near 800 nm, though receiving area, cooling power, dark noise and qualification matter. An inspected H 16722-50 specification gives 15% typical QE at 800 nm with a 5 mm cathode; this is not exact 777.4 nm PDE or a complete low-power system. A tiny high-PDE APD still faces the wide-field etendue requirement.

Comparable sensitivity must mean comparable detection probability versus incident aperture photons for specified source spectra, time windows, field positions and backgrounds. Equal output voltage, nominal QE, NEP or event counts does not ensure that. MMIA's nominal red aperture is 2.3 mm versus 1 mm in UV, but its Table 5 total efficiencies 1.6% versus 13.6% give red/UV A times PDE about 0.622, not automatically equal thresholds. Other aggregate calibration values differ and should not be silently substituted.

A red non-detection must be an upper confidence limit with calibrated live time, bias, noise, saturation, recovery and acceptance. Zero observed counts with exactly known zero background gives an ideal 95% mean-signal upper limit 2.996 counts; actual background, dead time and nuisance parameters change the procedure. An overloaded passive APD can register fewer counts as true activity grows. A narrow simultaneous window can also miss delayed thermal emission; Leal et al.(2026) selected direct-view return strokes have 22.7-58.3 microsecond red-minus-blue peak offsets, not proof of red absence at blue onset or for a 3 ms window.

Most importantly, no universal positive 777/337 lower bound for every weak thermal alternative was established. Blue-rich components can occur within ordinary lightning, and a UV-only particle artifact can pass a red-null rule. The criterion can be valuable but needs independently labeled controls and joint sensitivity/false-classification tests; it is not unique proof that no thermal channel formed.

**Corrections retained.** Red non-detection is a confidence statement, not zero emission. Red sensitivity must be compared in photon terms through the whole instrument. A blue-first peak does not by itself demonstrate full-event red absence.

$$P(N=0|S)=\exp(-S); S_{.95}=-\ln(0.05)=2.996$$

Ideal zero-count upper limit. Conditions: Known zero background, unit-valid live time and independent Poisson counts; not a general ratio confidence procedure.

$$\epsilon_{\text{false\_null}} = P(\text{red accepted as null} \mid \text{physical alternative, full chain})$$

Measure the relevant classification error directly. Conditions: Include spectrum, delay, field, background, health and selection.

**Manufacturer option:** GaAs PMTs are an alternative to low-red-QE multialkali and APDs.

**Flight design and failure examples:** MMIA nominal acceptance and APD saturation must retain exact conditions.

**Physical control evidence:** Temporal/spectral alternatives and author red-zero flags do not establish mission class purity.

**Still needed.** Both full-chain photon-scale spectral/field response, background/noise, live time and impulse response, including dead time, saturation and recovery Red-channel upper-limit coverage and joint false-negative/false-classification performance using calibrated injections and representative source controls

**Next inputs/tests.** Physically justified red search window, health/bias criteria, confidence rule and source-family spectral/delay assumptions

Related fresh calculations: R4-N04, R4-N09, R4-N10.

Sources: [S053]; [S056]; [S058]; [S066]; [S078]; [S079]; [S103]

## E-17 - Cross-calibration of different detector technologies for a trustworthy ratio.

Cross-calibrate the channels at a common physical reference plane using traceable spectral photon flux. Measure the complete spectral, field, pupil, polarization, temperature and intensity response, not just electrical gain. Use overlapping calibrated attenuation ranges and an independent monitor so that changing source intensity is not mistaken for detector gain or efficiency. The actual science-band filter and entrance optics must be in the path for end-to-end response.

Different technologies need different internal diagnostics: PMT charge/gain distributions, counting discriminator efficiency, APD multiplication/excess noise and SiPM correlated avalanches are not equivalent. Separate gain calibration from absolute incident-photon efficiency. A common pulse source can reveal relative delay, impulse response, dead time and recovery, which matter when an instantaneous 337/777 ratio is formed from different waveforms.

Propagate shared uncertainties and covariance. A common source calibration can cancel part of a ratio uncertainty, but wavelength-specific reference errors, field mismatch and spectral assumptions may not cancel. For a nonimaging instrument with unknown source angle, use an independently localized source or a conservative field-dependent response envelope. A central on-axis calibration cannot certify every location.

CALSPEC provides useful stellar spectra covering both target bands. Its normalization accuracy near 555.75 nm vacuum must not be treated as identical absolute accuracy at 337 nm. On-orbit stellar transfer also needs a view of the star: nominal nadir pointing in a 60-90 degree field at 550 km is Earth-filled. Maneuver constraints, scene backgrounds and response maps are part of the calibration design.

**Corrections retained.** Equal electrical gains are not equal photon response. Single-photoelectron gain calibration does not certify absolute PDE. Shared calibration uncertainty may cancel partly; wavelength/field-specific uncertainty remains.

$$R_{\text{ph}} = (C_{337} / \epsilon_{337}) / (C_{777} / \epsilon_{777})$$

Schematic corrected photon ratio. Conditions: Counts must be background/live-time corrected with valid likelihood; integrate actual spectra and time responses. Near a red null use an upper limit, not division by zero.

$$\text{Var}(\log R) = \text{Var}(\log X) + \text{Var}(\log Y) - 2 \text{Cov}(\log X, \log Y)$$

Shared systematic terms can cancel or reinforce. Conditions: Small-error illustrative approximation, not a sparse-count ratio confidence interval.

**Traceable calibration method:** Photon-scale calibration and stellar references have documented scope.

**Measured instrument context:** Relative-channel timing and optical response require actual assembly characterization.

**Still needed.** Traceable common-source calibration across each channel spectrum, field, pulse fluence and operating temperature with overlapping attenuation ranges Relative delay/IRF and systematic covariance, plus repeated stability checks and independent reference monitoring

**Next inputs/tests.** Photon reference planes and air/vacuum coordinate conventions; ratio definition for unequal time responses and selection rules

Related fresh calculations: R4-N10.

Sources: [S040]; [S048]; [S066]; [S068]; [S075]

## F-18 - On-orbit gain drift, absolute radiometric stability and peak brightness versus current.

Use several complementary calibration observables. An internal monitored LED can track repeatability and some gain changes; a full-path external reference can constrain entrance optics/filter/PDE drift; electrical injection checks readout gain, timing and offset but not photon efficiency. Reference-source and monitor drift themselves need redundancy or independent constraints. A reference bypassing the entrance optics cannot measure their contamination or transmission loss.

A single mean LED reading measures the product of LED photons, detection efficiency and multiplication gain. Under a validated Poisson photoelectron model, externally triggered illuminated and blank charge distributions, including no-signal pulses, can identify multiplication gain and variance separately from mean intensity. They still identify occupancy=photons times efficiency, not its two factors. Source intensity fluctuations, SiPM correlations, afterpulses, saturation and threshold truncation require expanded models.

Flight examples illustrate architecture rather than a Cube Sat accuracy guarantee. ISUAL's mainly-red internal LED response and HV corrections do not directly measure 337 nm PDE aging. OMPS working/reference diffuser schedules support long-term response tracking over a defined UV range, but their accuracy does not transfer to this design. CALSPEC stars offer another route if spacecraft attitude and full-path access permit it; on/off slews of a wide field change Galactic/stellar and terrestrial backgrounds. A favorable Poisson star-count budget does not prove percent-level absolute calibration.

Finally, absolute brightness is not a unique current meter. Photon production depends on electron energy distribution, reduced field E/N, excitation volume, quenching and source history; cloud transport and view geometry then alter the observed peak. Current, current moment and radio-inferred source parameters are different quantities. AIRFLY's measured 5.61 photons/MeV high-energy fluorescence yield is not a streamer photons-per-ampere calibration. A current relation requires a kinetic/radio/transport forward model and independent measurements.

**Corrections retained.** Internal LED mean response is a product, not a unique gain/PDE measurement. Published visible or reference-wavelength stability is not automatically 337 nm absolute stability. Absolute photons do not alone identify discharge current.

$$E[Q_{\text{light}}] - E[Q_{\text{blank}}] = \Phi \epsilon q_{\text{bar}}$$

Mean charge combines incident photons, photoelectron efficiency and mean multiplication charge. Conditions: Linear independent-photoelectron model; source fluctuations and backgrounds require treatment.

$$\text{Var}(Q_{\text{light}}) - \text{Var}(Q_{\text{blank}}) = \mu q_{\text{bar}}^2 F_q; \mu = \Phi \epsilon$$

Charge fluctuations and zero occupancy can help estimate gain. Conditions: Acquire all triggered pulses; no unknown truncation or unmodeled correlations.

$$\text{brightness} = \text{transport}\{ \text{excitation}(E/N, n_e, N, \text{volume}, \text{time}, \text{quenching}) \}$$

A source-current inference is an inverse problem with additional physical parameters. Conditions: Independent validation required; current and current moment must be distinguished.

**Calibration identifiability method:** Charge-distribution and occupancy methods separate some gains while retaining photon-efficiency ambiguity.

**Flight calibration heritage:** ISUAL/OMPS/OMI examples have wavelength, path and correction limits.

**Source physics constraint:** Fluorescence yield, field measurements and radio current inversion are not a universal current law.

**Still needed.** Independent optical reference/monitor stability and full-path throughput/PDE drift at science wavelengths, with separate multiplication-gain and offset diagnostics. If using stars, actual attitude/path/field response and differential-background covariance; if inferring current, independent current/radio-optical/source-condition calibration

**Next inputs/tests.** Observable calibration paths, schedules, celestial visibility, full occupancy/blank acquisition and source-current/transport forward model

Sources: [S040]; [S043]; [S044]; [S049]; [S050]; [S052]; [S099]; [S104]; [S109]

## F-19 - Ground calibration/characterisation and facilities.

Ground characterization should establish the delivered receiver's photon-scale response and uncertainty, not merely confirm that it produces an output. Measure spectral response across both passbands and the full detector-sensitive rejection range; field/pupil/polarization maps; temperature dependence; absolute throughput/PDE; linearity, dynamic range and saturation/recovery. Include cross-channel timing, clock accuracy, analogue/ADC impulse response and trigger selection.

Noise measurements must use the actual detector, bias, cabling, HV enclosure and estimator. Acquire dark distributions/PSD, afterpulses/correlated avalanches, rare bursts and particle/bright-light artifacts, not only RMS. Injection tests should span faint leading edges, strong backgrounds, and pulses exceeding 3 ms, with onset randomized against the clock. Calibrate attenuation and retain no-signal triggers where required by the statistical estimator.

Qualification adds vibration/shock, thermal-vacuum, HV behavior, materials/outgassing, contamination, daylight/sun protection, radiation and recovery tests for the selected assembly. Repeating calibration before and after these tests separates survival from maintained science performance. A reference detector or power standard must have a traceability chain and uncertainties appropriate to 337/777 nm and the receiving geometry.

NPL, PTB, NIST and ESA optical facilities provide documented relevant capabilities, but spectral coverage alone is not an accepted service for this exact large-field, pulsed receiver. The campaign establishes no institute affiliation or facility access on behalf of this assistant. Obtain an agreed scope, uncertainty budget, reference planes and acceptance criteria from the chosen laboratory before treating a calibration as available or achieved.

**Corrections retained.** Facility capability is not an agreed calibration uncertainty or booking. Surviving environmental tests is not the same as preserving calibrated sensitivity.

measurement uncertainty includes reference, geometry, spectrum, temperature, repeatability, linearity and drift

Repeatability alone is not the absolute uncertainty. Conditions: Retain covariance for the two-channel ratio and selection effects for faint pulses.

**Documented facility capability:** Relevant traceable calibration and optical test routes exist with configuration-specific limits.

**Calibration method:** End-to-end noise/response methods and spectral uncertainty must match the receiver.

**Still needed.** Configuration-specific traceable spectral/angular/pulsed receiver calibration with stated uncertainty  
Noise/linearity/trigger/timing/bright-light recovery, environmental qualification and contamination/radiation tests for selected build

**Next inputs/tests.** Facility-agreed spectral range, aperture/FOV, vacuum/pulse capabilities, access and accepted test plan

Sources: [S041]; [S047]; [S048]; [S051]; [S052]; [S075]

## F-20 - Laboratory 337 nm source with 30 us rise and >3 ms duration.

A near-UV LED with a suitably fast current driver is the most practical programmable end-to-end source to investigate. The emitted light, not the electrical drive command, must demonstrate the desired 30 microsecond rise and greater-than 3 ms duration at the selected operating current and temperature. A fast reference photodiode and oscilloscope can verify bright-source timing without claiming that a PIN receiver detects the faint orbital signal.

The inspected M 340 L 5 specifies 340 nm with 10 nm FWHM, so it is not a monochromatic 337.1 nm source. It can test the integrated band response if its spectrum and the instrument filter capture are calibrated. The previously cited LEDD 1 B transition values, about 51 microseconds rising and 79 microseconds falling under its test conditions, are too slow to certify a 30 microsecond optical rise. Use a driver whose loaded optical performance is measured rather than assume its modulation setting is sufficient.

A nitrogen 337 nm laser provides a closer wavelength but typically short individual pulses; the color match does not reproduce a millisecond plateau. Pulse trains, modulation or fluorescent sources introduce additional timing/statistical/afterglow assumptions. An actual discharge can supply relevant spectra and complexity but is harder to use as a stable calibrated waveform standard.

Build the testbed with independently monitored output, traceable attenuation, light-tight baffling and calibrated coupling to the entrance. Test several intrinsic shapes, including shallow/slow ramps, multipulses and bright-to-faint sequences. The goal is to characterize detection, red upper limits and timing over the required photon range, not

only display one attractive oscilloscope trace.

**Corrections retained.** A nominal wavelength or driver bandwidth does not certify the emitted optical waveform. The cited LEDD 1 B example is not a demonstrated 30 microsecond source.

$$N_{\text{band}} = \text{integral } E_{\text{pulse}} \lambda \lambda / (h c) T(\lambda) d \lambda$$

Calibrate useful photons through the actual spectral response. Conditions: Measured LED spectrum, attenuation and pulse energy; no arbitrary full-width multiplication.

**Manufacturer test source specs:** M340L5 and LEDD 1 B give specific spectrum and transition limitations.

**Calibration heritage:** Pulsed 337 nm sources can calibrate detector systems, but temporal/source transfer must be specified.

**Still needed.** Optical waveform measured by a sufficiently fast reference at actual drive/temperature: 30 us rise, >3 ms duration, stability and recovery Spectrum/filter capture and calibrated attenuation from faint through overload, with stray-light control

**Next inputs/tests.** Actual LED/source and fast driver/load; target 337 band equivalence and reference detector calibration

Sources: [S039]; [S042]; [S045]; [S046]

## G-21 - Can 2-4 kg/5-10 W deliver a useful event rate at 550 km?

A 2-4 kg, 5-10 W optical head is physically plausible given flight photometer heritage, but the requested useful detection rate is not yet demonstrated. Sensitivity, classification, bright-event survival and orbital yield are distinct requirements. A component power number excludes HV, cooling, ADC/FPGA, heaters, safing and spacecraft interfaces unless explicitly included. No packaged 25 mm/wide-field 1U optical design or end-of-life total power budget has been accepted.

The campaign recovered absolute observed 337 nm examples and public plotted waveforms. For one selected Bai et al.(2023) event, baseline-subtracted finite-window integration from-0.2 to 3 ms gives about  $7.53e-9 \text{ J/m}^2$  at the original spacecraft geometry, or  $1.28e10 \text{ photons/m}^2$  near 337.1 nm. Its selection favored a fast, intense event. It is not intrinsic source energy, a faint completeness limit, or a 550 km measurement. Do not apply cloud attenuation to an observed spacecraft fluence a second time; an inverse-square range adjustment alone is conditional on unchanged directional source/cloud geometry.

Published selected peaks also expose the bright-end problem. The reviewed source ledger's 25 mm/20% examples imply roughly 0.33-24 GHz photoelectron arrival rates for selected peaks, far beyond a simple 17 ns counter's linear regime. Enlarging aperture does not exclusively improve faint sensitivity; it can create saturation and bright-light recovery requirements. Parallel gain/attenuation or another dynamic-range architecture may be needed.

Useful rate requires the joint source-fluence, class, altitude, depth, cloud and geographic/time distribution, including non-detections and calibrated selection. ASIM event cohorts overlap, and particle-rejection algorithm changes alter high-latitude samples. Global selected BLUE rates, radio NBP fractions and the spacecraft footprint cannot be multiplied into a justified polar yield without their common exposure/selection. Night at the cloud, shadow at the emitting layer, spacecraft eclipse, HV enabled state, valid telemetry and observing duty cycle are distinct. The fresh field-of-view population calculation explores unknown slope assumptions; it does not fit a luminosity function or predict events/day.

**Corrections retained.** Observed spacecraft fluence is not pre-cloud source output and must not be attenuated twice. Selected bright events cannot define the faint population or unbiased orbital rate. Larger aperture also raises background and bright-end saturation.

$$N_{\text{useful}} = \text{integral population}(x) \text{ exposure}(x) P_{\text{detect}}(x) P_{\text{classify\_correct}}(x) dx$$

Rate depends on joint conditions, not independent scalar fractions. Conditions: x includes geometry, time, cloud, class, brightness, background and receiver state.

$$S = \Phi_{\text{ap}} A \eta$$

Observed aperture-plane photon fluence can be replayed into a hypothetical receiver. Conditions: No additional cloud attenuation on already observed data; range/angle changes need explicit assumptions.

**Selected calibrated observation:** BATH figure arrays support a finite-window observed fluence with published calibration and original geometry.

**Selected population and pipeline:** Survey counts, cohort overlaps and algorithm changes do not supply a completeness-corrected polar luminosity function.

**Flight architecture:** MMIA establishes compact photometer heritage, not the proposed head budget or aperture.

**Still needed.** Faint source/dual-band population with calibrated completeness and non-detections. Packaged optical/electronic/thermal/power design, field response, backgrounds and end-of-life injection-recovery. Actual orbit/time/exposure, health/safing, telemetry and false-classification controls.

Related fresh calculations: R4-N06, R4-N09.

Sources: [S066]; [S098]; [S100]; [S101]; [S102]; [S108]; [S110]

## G-22 - What assumptions or physics are missing?

The largest correction is to treat this as a coupled inverse and classification problem rather than a single photon-count calculation. Optical brightness, cloud depth, source current and physical discharge class are not uniquely interchangeable. A fast blue rise with weak red emission is informative evidence, but alternative source histories, ordinary-lightning components, cloud paths and instrumental artifacts must be tested.

Keep four photon reference planes separate: emitted source photons, cloud-exiting angular light, aperture photons and detected photoelectrons/registered counts. Keep source and received spectra, time definitions, bandwidth units and air/vacuum wavelength coordinates explicit. The earlier universal 3 ms source duration, universal amplifier floor, constant aurora assumption and unqualified 4 nm filter response are not retained as facts.

The full source pipeline is part of the measurement. Selected survey counts depend on trigger/live time, HV state, particle vetoes, threshold/background recursion, processing version and association windows. Literal ISUAL 337 positive/777 zero flags are reproducible catalogue labels, not independently verified thermal false positives or physical zero-red events. A published corrected waveform cannot be accused of raw-dead-time distortion merely because a separate raw mean-response diagnostic exhibits it.

The most effective remaining program is a bounded sequence: choose a physically feasible optical/detector candidate; measure its photon-scale, spectral/angular/timing/noise/dynamic-range response; validate source/cloud hypotheses with realistic injections and independent labels; then integrate useful exposure over the actual orbit and source population. Obtain independent full-path calibration and end-of-life tests before using peak brightness as a current estimator. Additional literature reduces uncertainty but cannot replace the missing selected-instrument and faint-population measurements.

**Corrections retained.** Do not collapse detection, timing measurement, class identification and current inversion into one threshold. Preserve measurement/model/example/access states and independent cohorts. More decimal places or more papers do not replace missing mission inputs.

evidence states: measured / conditional model / method / missing

A source link is not a mission validation statement. Conditions: Retain original units, geometry, selection, access and uncertainty.

**Crossstream qualification:** Source selection, red-null controls and current inversion retain empirical/access limits.

**Method and heritage:** Transport, detector and calibration principles supply tests without full mission closure.

**Still needed.** Selected receiver calibration and end-of-life response. Realistic source/cloud/noise classes and independent physical labels. Unbiased joint population/exposure and validated operational false-event control.

Sources: [S052]; [S066]; [S077]; [S078]; [S097]; [S100]; [S103]; [S109]

## Fresh calculations and their limits

These studies answer conditional questions and test algorithms. They do not establish a polar sky climatology, a faint-event population, a physical depth classifier or accepted flight hardware. Counts of cases or packets describe computation, not independent observations.

### R4-N01 - Clear-air direct Rayleigh transmission

Recomputed the 337.1 nm molecular cross section and dry standard-atmosphere number column, with an independent pressure-column comparison and grid check. This is a direct no-collision factor, not total cloudy directional transmission.

Additional direct-ray table uses exact inverse-square geometry for 25 mm at 550 km, source 15 or 18 km, then multiplies the reference Rayleigh factor and  $\exp(-\tau_{\text{cloud}})$ . The 20% column is a separate illustrative detection probability. It is not used to infer an intrinsic source yield.

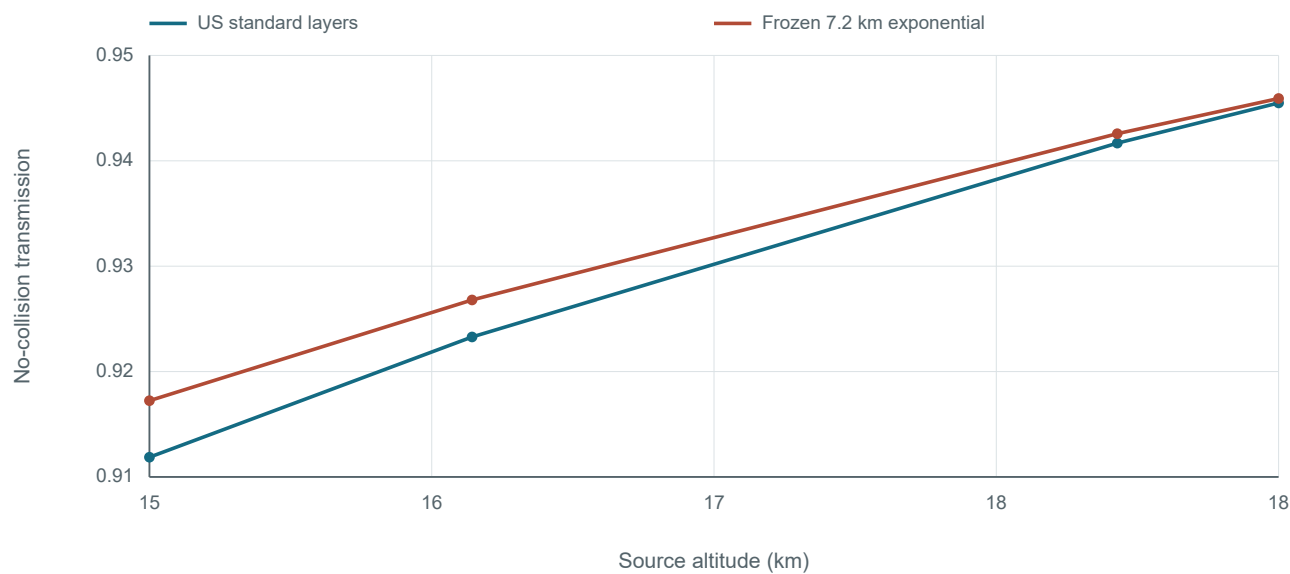
*Dry reference vertical column. No cloud, ozone, aerosol or real weather included.*

| Altitude km | Standard tau_R | Standard direct T | Frozen-exp direct T |
|-------------|----------------|-------------------|---------------------|
| 15          | 0.08876        | 0.9151            | 0.9206              |
| 16          | 0.07589        | 0.9269            | 0.9306              |
| 18          | 0.05549        | 0.946             | 0.9469              |
| 18.5        | 0.05132        | 0.95              | 0.9504              |

*Direct-only illustrative 25 mm aperture. Standard dry Rayleigh plus stated overhead particle optical depth. Last column adds assumed 20% end-to-end detection probability; it is not photon transmission. No scattered return, ozone or aerosol.*

| Source km | Cloud tau_above | Direct survival | Aperture photons/emitted | Detected events/emitted |
|-----------|-----------------|-----------------|--------------------------|-------------------------|
| 15        | 0               | 0.91507         | 1.2488e-16               | 2.4977e-17              |
| 15        | 0.1             | 0.82799         | 1.13e-16                 | 2.26e-17                |
| 15        | 0.3             | 0.6779          | 9.2516e-17               | 1.8503e-17              |
| 15        | 1               | 0.33664         | 4.5942e-17               | 9.1884e-18              |
| 15        | 3               | 0.045559        | 6.2176e-18               | 1.2435e-18              |
| 15        | 10              | 4.1544e-05      | 5.6697e-21               | 1.1339e-21              |
| 18        | 0               | 0.94602         | 1.3057e-16               | 2.6114e-17              |
| 18        | 0.1             | 0.85599         | 1.1814e-16               | 2.3629e-17              |
| 18        | 0.3             | 0.70083         | 9.6727e-17               | 1.9345e-17              |
| 18        | 1               | 0.34802         | 4.8033e-17               | 9.6067e-18              |
| 18        | 3               | 0.0471          | 6.5006e-18               | 1.3001e-18              |
| 18        | 10              | 4.2949e-05      | 5.9278e-21               | 1.1856e-21              |

Direct molecular transmission above high sources



Fresh arithmetic; differences reflect reference density profiles, not event-specific weather. No diffuse photons included.

**Limits.** Direct/ballistic no-collision transmission only. Rayleigh-scattered photons are not all absorbed or necessarily outside the full instrument response. Cloud attenuation can multiply this factor for the direct ray  $e^{-\tau_{\text{cloud}}}$  only; total diffuse directional fluence requires radiative transfer and cannot be obtained by this exponential alone. This is a clear dry reference atmosphere; no aerosol, ozone, real polar seasonal weather, source spectrum, or finite-band weighting included. At/above cloudtop,  $\tau_{\text{cloud\_above}}=0$  does not remove the delayed contribution of downward photons returning from the cloud below.

Sources: [S032]; [S034]

Reproducibility: analysis/analytic/execution\_receipt.json; analysis/analytic/rayleigh/Rayleigh\_standard\_vs\_frozen\_337\_audit.json.

R4-N02 - An above-top reflector can increase nadir light and delay it

Re-ran 108 analytic cases for an isotropic point above a flat instantaneous Lambert reflector. Independent radial integration and escape/threshold checks passed. In the surface limit, nadir fluence relative to vacuum is  $1+2\rho$  while total upward escape is  $(1+\rho)/2$ ; directional gain therefore does not create photons.

The reflected waveform is a geometric convolution with a linear rise to an indefinite plateau. Its 10-90 rise is not an impulse arrival percentile or onset-to-peak duration.

surface limit: directional factor= $1+2\rho$ ; upward escaped fraction= $(1+\rho)/2$

delay= $[\sqrt{h^2+r^2}+\sqrt{H^2+r^2}-(H-h)]/c$

Ideal 15 km plane, 550 km observer, 60 degree circular field,  $\rho$  0.8 and 30 us intrinsic 10-90 linear rise.

| Height above plane m | Nadir/vacuum fluence | Output rise us | Min reflected delay us |
|----------------------|----------------------|----------------|------------------------|
| 0                    | 2.6                  | 30             | 0                      |
| 1                    | 2.6                  | 30             | 0.006671               |
| 100                  | 2.599                | 30.42          | 0.6671                 |
| 1000                 | 2.586                | 38.78          | 6.671                  |
| 3000                 | 2.558                | 78.71          | 20.01                  |

**Limits.** More lower reflectance may add photons; this does not mean more OVERHEAD extinction must increase fluence Factor 3 for  $\rho$  1 is this to nadir limit, not universal Mie/ice cloud bound Photon hemisphere escape fraction  $\leq 1$  even when directional ratio  $> 1$  Geometry-only rise changes are not claimed real depth calibration or validation of 30-80 versus 200 us classifier Raising telescope altitude mainly changes dilution; pulse broadening depends on path differences, not common flight time Isotropic point source above plane; finite aperture small compared with range Instantaneous local Lambert reflection with assumed  $\rho$ , no residence time/lateral transport inside cloud Infinite flat plane and unlimited radiance field; detector circular FOV truncates received reflection

Vacuumaboveplane; no Rayleigh, aerosol, ozone, Earthcurvature, sourceextent, fieldresponse/electronics/sampling  
Infiniteplateauafterintrinsiclinear-rise; nofinite 3 mspulseendordroop No mappingofphotooverheadcloudtau. h=0  
meanslimitingjust-abovesurfaceposition, notanembeddedcloud-topscatteringboundary

Sources: [S112]

Reproducibility: analysis/analytic/reflection/derivation\_and\_qualification.json;  
analysis/analytic/reflection/conditional\_reflection\_and\_rise.csv.

R4-N03 - Depth and diffusion strength are not uniquely identifiable

Re-ran 48 ideal half-space diffusion/absorption examples. The first-exit density is  $L/\sqrt{4 \pi D} t^{(-3/2)} \exp[-L^2/(4 D t)-\gamma t]$ . Cases with identical  $L^2/D$  and  $\gamma$  have the same entire kernel.

The computed leading 10-90 coefficient is 0.0743277  $L^2/D$ , close to the published rounded 0.0742. The nonabsorbing mode is  $L^2/(6 D)$ ; their ratio is 0.44597, so the definitions are quantitatively different.

This diffusion density is a plane first-exit quantity integrated over transverse position, not finite-aperture directional radiance. Diffusion has noncausal early support and cannot replace transport near the ballistic front.

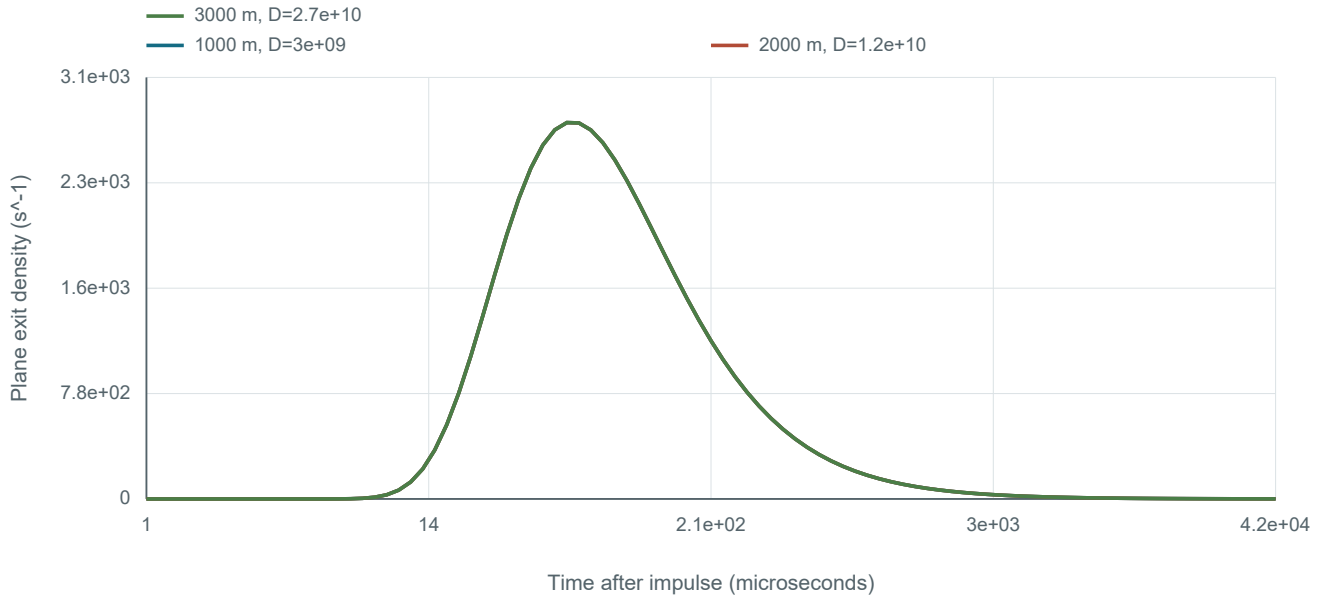
Identical-kernel mathematical counterexample; not three measured clouds.

| Depth m | D m 2/s | L 2/D s   |
|---------|---------|-----------|
| 1000    | 3e+09   | 0.0003333 |
| 2000    | 1.2e+10 | 0.0003333 |
| 3000    | 2.7e+10 | 0.0003333 |

Nonabsorbing diffusion fraction exited within 3 ms at D 3 e 9 m 2/s. It is not aperture capture.

| Input 10-90 us | Mode us | Depth m | Exit fraction by 3 ms |
|----------------|---------|---------|-----------------------|
| 5.5            | 12.33   | 471.2   | 0.9116                |
| 30             | 67.27   | 1100    | 0.7954                |
| 80             | 179.4   | 1797    | 0.6719                |
| 200            | 448.5   | 2841    | 0.5031                |

### Different depths, same ideal diffusion kernel



*Coincident curves are an exact-model identifiability example. They are not finite-cloud observer signals, and diffusion is unsuitable for the true early ballistic front.*

**Limits.** Parabolic diffusion has a causal non-zero  $t < t_{\text{light precursor}}$ ; report flags when 10% threshold itself is unphysical. Not a near-time RTE benchmark. Semi-infinite homogeneous medium with absorbing plane and instantaneous delta emission; no finite cloud base, phase function, source extent, upward ballistic term or internal cloud top boundary.  $A > 3$  ms observed pulse is not assumed 3 ms intrinsic emission or dwell time; real emission requires convolution Gamma uniform everywhere, not spatial ozone/Rayleigh/ice profile; example 0.1/10/50 not empirical confidence intervals. All-time escape and 3 ms capture belong to this model; no actual NBE energy correction Model D values and top 18 km in counter example are conditional, not independent height observations Published 5.5 us model-based subsample fit does not prove general 5.5 us measurement precision at 10 us binning Exact  $L^2/D$  whole-kernel degeneracy is a property of the parabolic diffusion PDE; finite-speed light transport can break it. All parabolic kernels have non-zero pre-flight tails. Passing  $t_{10} \geq L/c$  does not validate early-time radiative transport. 0.07432773536 versus the paper's 0.0742 is not an established published error; original Eq 6 bitmap was not retrieved.

Sources: [S100]

Reproducibility: analysis/analytic/diffusion/derivation\_and\_qualification.json.

### R4-N04 - Raw dead time can compress an apparent rise

Re-ran 84 nonparalyzable quasistatic mean-response cases. For a linear ramp, raw normalized output becomes  $f(1+x)/(1+xf)$ ,  $x = S \tau / (1+b \tau)$ . Its 10-90 rise divided by the true linear-ramp rise is  $(1+x)/(1+x+0.09 x^2)$ .

This diagnostic concerns raw uncorrected expectation. It does not demonstrate bias in a published corrected MMIA waveform, does not restore individual photons and does not produce a valid Poisson likelihood after correction.

$$m = r / (1 + r \tau)$$

$$\text{raw linear-ramp rise ratio} = (1+x)/(1+x+0.09x^2)$$

$$dr/dm = 1/(1-m \tau)^2; \text{ correction becomes ill-conditioned near saturation}$$

**Limits.** Only RAW uncorrected mean waveform shape; published corrected MMIA waveforms cannot be accused of this bias from this diagnostic No actual source brightness distribution or detector selected No afterpulsing, paralyzable holdoff, discriminator walk, gain sag, baseline estimation, electronics/sampling or count likelihood Stationary Poisson arrival mean response applied quasi-statically; not exact stochastic waveform Mathematical inversion recovers the mean only for a valid known model; does not restore lost photons or Poisson statistics Binwise inverse is nonlinear: expected inverse of measured count is not inverse of expected count A 200 us input can give raw ~ tens-us apparent rise when strongly saturated; this is not evidence faint events actually do so Simply enlarging aperture at fixed throughput raises mean rate; gain changes alone are not assumed to correct dead time

Sources: [S066]

Reproducibility: analysis/analytic/deadtime/derivation\_and\_qualification.json.

## R4-N05 - Auroral/background amplitude scenarios and exact Poisson thresholds

Re-ran 192 ideal detector-count scenarios with uniform received band-equivalent brightness 15, 100, 1000 or 2270 R, eta 0.2 and 50 darkcounts/s. A 2270 R amplitude is a selected historical scale, not a received uniform 4 nm polar measurement.

Exact Poisson tails set critical counts and 95% detection power. A hypothetical operational budget assumes 50000 starts/s, 86400 s and 3 families for 0.1 false trigger per day; actual correlated/overlapping searches and nuisance parameters need their own allocation.

*Assumed received band brightness; 60 degree circular field, 30 us window, eta 0.2, dark 50/s. High dead-time occupancy invalidates literal ideal-counter use.*

| Aperture mm | Band R | Rate PE/s | Signal PE 95% | r x 17 ns |
|-------------|--------|-----------|---------------|-----------|
| 1.0         | 15.0   | 1473      | 11.8          | 2.503e-05 |
| 1.0         | 2270.0 | 2.229e+05 | 34            | 0.003789  |
| 25.0        | 15.0   | 9.204e+05 | 57.79         | 0.01565   |
| 25.0        | 2270.0 | 1.393e+08 | 556.8         | 2.368     |

**Limits.** NoKpclassoroccurrenceassigned Noextrapolationfrom 10 degreeaircraft FOV tofull 60/90 degreearc  
Nocloudreflectionorlimbtonadirtransfercomputed Noactualsourcephotonfluenceorpopulationinferred  
Noactualfilter/PDE/temperature/radiationdrift NoPMT multiplicationexcessnoise, SiPM correlatednoise, particles,  
baselineuncertaintyordeadtimein Poissonlikelihood Single-window 5 sigmatailisnotglobalfalse-triggercontrol;  
operationalallocationishypothetical 50 kstarts/s\*86400 s\*3 families

Sources: [S025]; [S026]; [S113]

Reproducibility: analysis/analytic/auroral\_counts/conditional\_auroral\_count\_scenarios.json;  
analysis/analytic/auroral\_counts/conditional\_auroral\_count\_scenarios.csv.

## R4-N06 - Field size versus an unknown source-brightness law

Re-ran 216 spherical-geometry sensitivity cases with an assumed cumulative source number  $N(>yield)$  proportional to  $yield^{(-\alpha)}$ . Alpha and normalization are not measured or fitted.

The wider field raises covered area but also background, off-axis range and projection losses. The 90/60 relative yield can change sign of preference as alpha changes. The weighted exposure area uses an arbitrary  $1 \text{ e } 20$  photon pivot only for units; it is not an assumed event output or an actual effective mission exposure.

*Hypothetical  $3\text{e-}9 \text{ Wm}^{-2} \text{ sr}^{-1} \text{ nm}^{-1}$  background, 25 mm, 17 km source shell; no cloud loss. Not events/day.*

| Assumed cumulative slope alpha | 90/60 relative yield | 90 degree edge/axis threshold |
|--------------------------------|----------------------|-------------------------------|
| 0.5                            | 2.233                | 3.093                         |
| 1                              | 1.597                | 3.093                         |
| 1.5                            | 1.167                | 3.093                         |
| 2                              | 0.8711               | 3.093                         |
| 2.5                            | 0.6632               | 3.093                         |
| 3                              | 0.5139               | 3.093                         |

**Limits.** Noactual NBE brightnessdistribution, geomagnetic/cloudfrequency, radio-opticalselectionoroccurrencerate  
Noopticalétenduefeasibilityforchosenentrance/detector/filter; separatelyqualifiedconstraintsstillapply Fixedsourcecollected  $A\cos(\theta)$ ,  
noextraunknown  $C(\theta)$ maporvignetting Nooff-axiscloudescapeanisotropy, sourceextent, windowspill, realice/aerosol/gasorcloudreflection  
Countdetectiononly: usefultscienceyieldfurtherrequiresriseprecision, 777 upperlimit, associationandfalsepositivevalidation  
Noorbitalnight/cloudfraction/attitude/safe-mode/SAA/live-timeorfollow-upcoverage; actualrateidentifiabilityremainsopen

Powerlawandspatialuniformityarehypothetical, notfitstotwelve ASIM events Bright-enough population WEIGHT proxy, not an orbital event rate or a full detection-probability integral.

Sources: [S110]

Reproducibility: analysis/analytic/fov\_population/derivation\_and\_qualification.json.

R4-N07 - Actual reference continuum and starlight data folds

Re-ran Noll processed-mean spectral folds and Bianchi coarse-spectral sky-cube hemisphere examples. Source data are real/model-published inputs, but the target geometry and ideal filters are conditional.

The Noll extraction removes strong lines and modeled celestial components. Bianchi covers stellar components, not Moon, zodiacal or airglow, and its spectralgrid near 337 nm is much coarser than 4 nm. Neither is a total polar scene distribution.

Noll processed mean through ideal top-hats centered at 337.1 in the table convention.

| Width nm | Integrated Wm <sup>-2</sup> sr <sup>-1</sup> | Band mean Wm <sup>-2</sup> sr <sup>-1</sup> nm <sup>-1</sup> |
|----------|----------------------------------------------|--------------------------------------------------------------|
| 1        | 2.032e-09                                    | 2.032e-09                                                    |
| 2        | 3.933e-09                                    | 1.966e-09                                                    |
| 4        | 7.08e-09                                     | 1.77e-09                                                     |
| 8        | 1.258e-08                                    | 1.573e-09                                                    |

**Limits.** Mean 10633 selected 2009-2019 Cerro Paranal spectra, >=10 min exposure; Moonabovehorizonwithillumination>50% excluded. Not a polar or microsecond distribution. Continuum extracted by median/percentile filters; strong resolved lines removed, unresolved O2 UV bands retained partly. Extraterrestrial components modeled/subtracted; extinction and van Rhijn 90 km corrected. Not total night sky or total 777 line background. Header only says wavelengthnm. Official ESO says Xshooter pipeline wavelength in air; authors could have subsequently converted, not explicitly verified here. Fold centre 337.1 uses table convention; photonenergyuses nominal wavelength with <0.03% air/vac sensitivity. 4 component NMF is statistical; labelledcomponents must not automatically be treated as puremolecular emissions. 0.5 nmgrid/broad extraction smoothing cannot validate sub-nm filter choices. Totalmeans direct+interstellar-dust-scattered starlight; no zodiacal, moon, airglow. Opticalphotometry+stellar-atmosphere/extinction extrapolation, not a narrow 337 measurement. 99 logbins span~0.1-4.3 um: around 337 bracket~13 nm wide. Cannot infer actual 4 nm spectralfeatures or own covariance from tabulated broad-model errors. Hypotheticalsix cloudnormaldirections, noactualorbit/date/Sun/moon/cloudprofile. Not globalminimum/maximum or occurrenceweighteddistribution. Earthfilled nadir does not see this external field directly; need hemisphericillumination and cloud BRDF/atmosphericsscattering. Lambertalbedo.8 is an explicit example only. Cubeis HEALPix NESTED order 6 in celestial RA/Dec despite paper figures plottedin Galacticcoordinates. Do not reinterpret cube in Galacticcoordinates.

Sources: [S013]; [S017]; [S018]

Reproducibility: analysis/analytic/background\_components/new\_spectral\_background\_qualification.json.

R4-N08 - Optical/electronic design algebra with explicit assumptions

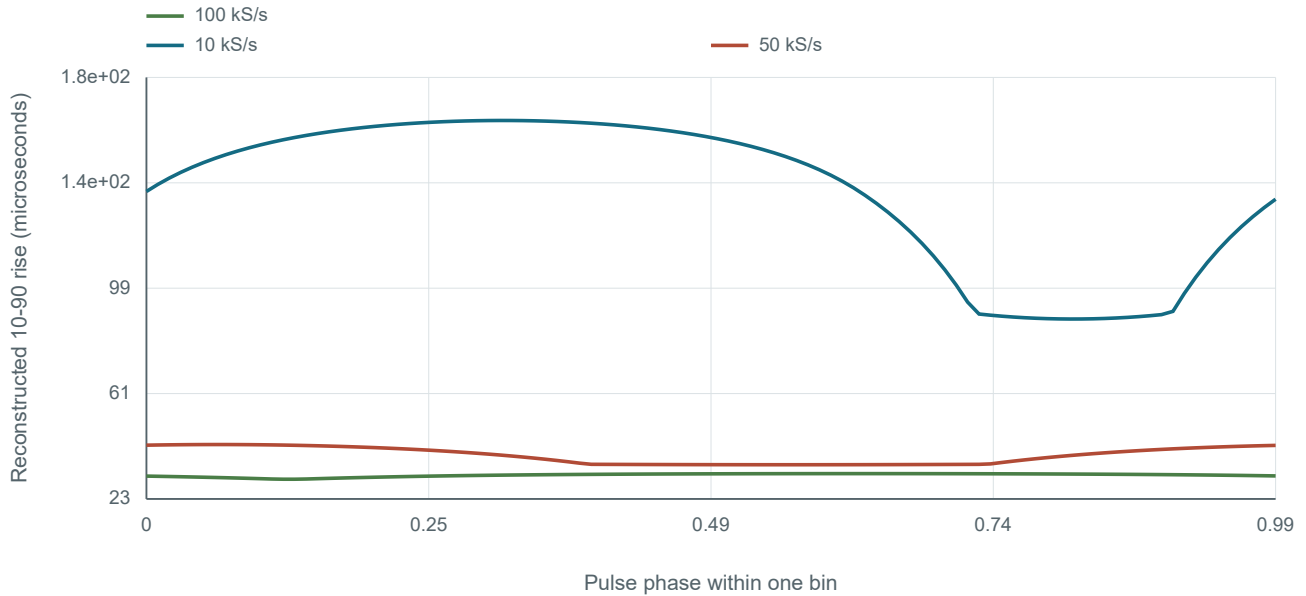
Fresh design suite contains 36 etendue bounds, 372 hypothetical Gaussian source/filter cases, 900 sample-phase examples, 9 AC-droop rows, 58 OD allocations, 72 dark-only NEP scenarios and 192 browser-budget references. Forty-eight independent Gaussian quadrature checks agreed at about 4.4e-16 maximum absolute difference.

These are algebra and sampling diagnostics. The Gaussian source is not N2 line reconstruction; dark-only NEP omits sky, amplifier, correlations and radiation; ideal etendue is a necessary bound, not a ray-traced layout.

Ideal air etendue: 25 mm entrance and 10 degree internal filter half-angle.

| Full circular field | Minimum detector mm 2 | Minimum clear filter mm |
|---------------------|-----------------------|-------------------------|
| 30                  | 32.88                 | 37.26                   |
| 60                  | 122.7                 | 71.98                   |
| 80                  | 202.8                 | 92.54                   |
| 90                  | 245.4                 | 101.8                   |

### Noiseless bin-phase bias for a 30 us linear rise



*Exact nonoverlapping bin averages with interpolation at bin midpoints. This is a particular noiseless estimator/model, not measured timing performance.*

**Limits.** No flight filter optimum, no measured electronics noise, no hardware qualification and no source-population inference.

Sources: [S073]; [S075]

Reproducibility: analysis/design/execution\_receipt.json; analysis/design/design\_results.json; analysis/design/etendue.csv; analysis/design/parametric\_filter.csv; analysis/design/sampling\_phase.csv; analysis/design/ac\_coupling.csv; analysis/design/blocking\_allocation.csv; analysis/design/dark\_only\_nep.csv.

### R4-N09 - Detection is easier than trusted morphology classification

Executed 81,000 synthetic signal trials across 81 scenarios: receiver-input 10-90 rises 30, 80, 200 us; plateau-equivalent 3 ms scales 100, 1000, 10000 PE; background 50, 10000, 1e6/s; sampling 10, 50, 100 kS/s. Amplitude, onset and background are fitted using a finite 10 ms prewindow and explicit gates.

A predefined profile-log-likelihood margin  $\ln 19$  selects accepted classifications. It is not automatically a calibrated 95% posterior probability or a 95% correctness guarantee. Rejected events, wrong accepted labels and interval uncertainty are all reported.

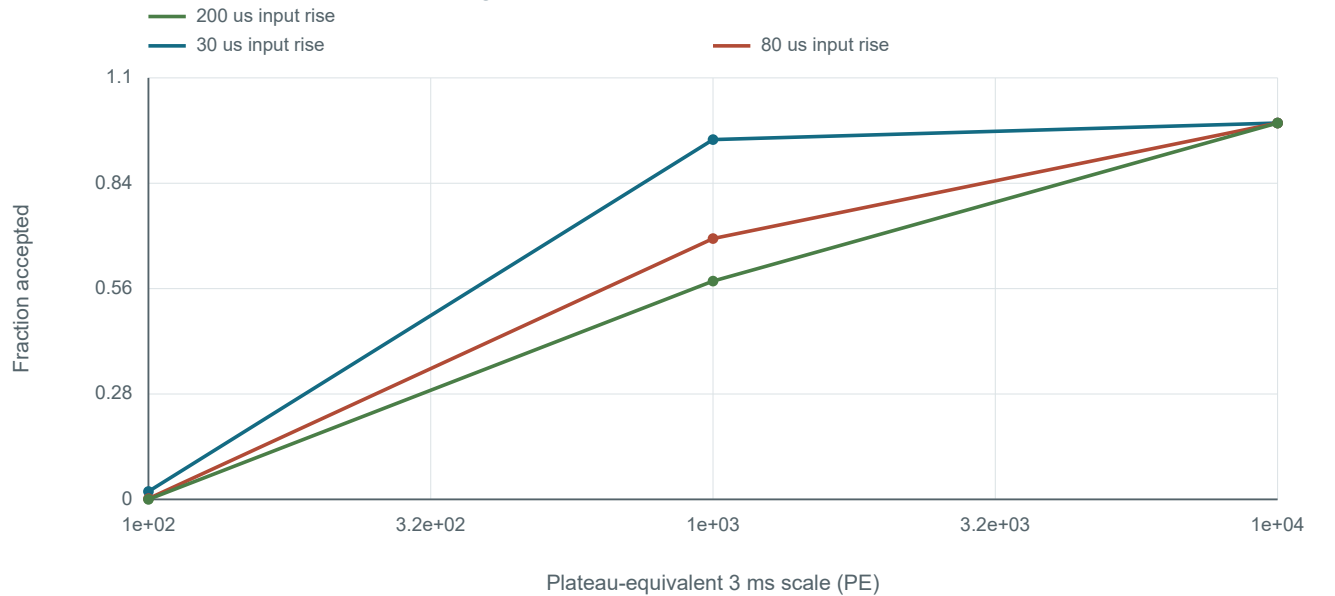
The plateau-equivalent scale is rate times 3 ms. Actual source totals are smaller because the linear ramp uses part of the finite 3 ms pulse. These are receiver-input morphology trials, not source-depth/class validation. Count-loss occupancy flags are diagnostics only; the generator remains ideal independent Poisson.

Independent profile-objective comparisons and exact seeded reruns passed. The known-template oracle has extra information and is an optimistic benchmark, not an achievable estimator promise.

50 kS/s, 1,000 trials per row. Accepted fast/slow labels use the predefined  $\ln(19)$  score selection. The last column reports wrong/accepted percentage and an individual two-sided exact 95% interval; it is not a posterior probability.

| Scale PE | b/s   | Rise us | Actual PE | Detected | Accepted | Wrong/accepted | Error% [95% CI]        |
|----------|-------|---------|-----------|----------|----------|----------------|------------------------|
| 100      | 50    | 30      | 99.38     | 1000     | 21       | 0/21           | 0% [0,16.11]           |
| 100      | 50    | 80      | 98.33     | 1000     | 2        | 0/2            | 0% [0,84.19]           |
| 100      | 50    | 200     | 95.83     | 1000     | 0        | 0/0            | undefined [n/a, n/a]   |
| 1000     | 50    | 30      | 993.8     | 1000     | 956      | 0/956          | 0% [0,0.3851]          |
| 1000     | 50    | 80      | 983.3     | 1000     | 693      | 4/693          | 0.5772% [0.1575,1.471] |
| 1000     | 50    | 200     | 958.3     | 1000     | 580      | 15/580         | 2.586% [1.455,4.23]    |
| 1000     | 1e+06 | 200     | 958.3     | 1000     | 8        | 5/8            | 62.5% [24.49,91.48]    |

Accepted fast/slow labels at 50 kS/s, background 50/s



Synthetic receiver-input shapes, unknown amplitude/onset, finite baseline. Acceptance alone is not correctness; the accompanying table includes errors and exact intervals.

**Limits.** This is a conditional synthetic receiver-morphology study, not a flight sensitivity/completeness validation. The classes mean 30/80/200 us 10-to 90% rises at a hypothetical linear receiver input after transport; they do not label source depth. Source brightness, cloud transfer, line spectrum, detector PDE and source occurrence population are outside this count-level calculation. The practical code has an external coarse onset bracket and a specified event gate. Blind stream triggering and a mission false-alarm rate are unvalidated. A fixed  $\ln 19$  profile-score margin is not calibrated 95% confidence. Always show accepted fraction, rejected fraction and the error interval together. The 3-class fast-subtype distinction is harder than the grouped fast-vs-slow test; these are separate decisions. Only exact model-matched templates and constant backgrounds are generated. Real independently labeled optical/radio controls are still needed. Post-counting electronic filtering, detector excess noise, afterpulses, saturation and deadtime are not simulated. 17 ns occupancy is an illustrative hardware flag, not Poisson restoration. Known-background red limits are invalid if a noisy finite baseline is silently substituted. The provided alternative uses a conservative Bonferroni construction. Red limits constrain expected registered counts in a specified window, not thermal-source absence. Selection, red-window timing, throughput and population ratios remain physical inputs. A useful mission event rate is NOT COMPUTABLE without an absolute received-fluence distribution, completeness and exposure definition. No empirical wide-FOV event rate is inferred from the conditional geometric/population proxy; source geography and coverage remain unknown.

Sources: [S116]; [S113]; [S067]

Reproducibility: analysis/statistics/statistics\_results.json; analysis/statistics/practical\_morphology\_scenarios.csv.

R4-N10 - Exact counts, finite-baseline limits and search control

Executed 63 deterministic count-inference controls and separate coverage/null Monte Carlo diagnostics with 200000 trials per configuration. The mathematical model is independent Poisson counts with stationary background and known on/off exposure ratio.

Known-zero-background zero counts gives the 95% upper mean 2.9957. The specified conservative finite-baseline construction with zero on and zero off counts gives 3.6889 under equal alpha splitting. This difference is a procedure/model change, not conflicting physics.

Individual discrete confidence procedures may be conservative. The retained initial individual 99.9% Monte Carlo discrepancy was not hidden or rerolled; the declared simultaneous 99% family audit overlaps the analytic coverage enclosures. Monte Carlo intervals diagnose implementation; coverage follows from the stated mathematical construction.

Unconditional coverage need not remain 95% after selecting only non-detections or accepted classes. Per-test alpha is not continuous-search false alarm. Dead time, overdispersion, unknown calibration and varying background require more models.

*Exact ideal count controls; limits concern expected detected source counts in the selected window.*

| Procedure/condition                             | Upper mean 95% |
|-------------------------------------------------|----------------|
| Zero counts, known zero background              | 2.99573        |
| Zero on/off, finite baseline, equal alpha split | 3.68888        |

**Limits.** Registered counts in nonoverlapping on/off windows are independent Poisson variables, before any deadtime/censoring issue. Source expectation  $s \geq 0$  is confined to on window; background stationary with common rate and known exposure ratio. Known-background upper bound requires externally known fixed  $b_{on}$ , not a finite-baseline plug-in estimate. Bonferroni alpha split is fixed before observing counts; total nominal  $\alpha = .05$ , default equal split. Limits cover expected detected source counts in the selected window, not emitted photons, current, peak rate, or source class. Per-test alpha is not a search false-alarm probability. A family bound needs the actual number of evaluated tests; operational overlapping-window trial count is unspecified. Rate times assumed 17 ns deadtime is only a diagnostic flag in the parent analysis. Flagging does not restore ideal Poisson counts; no Bernoulli-bin detector model is imposed here. Applying limits only after data-dependent selection or nondetection can change conditional coverage; unconditional bounds do not automatically survive that conditioning. Unknown backgrounds, drift, overdispersion, overlapping on/off windows, optical calibration and detector artefacts require separate models.

Sources: [S113]; [S114]; [S115]

Reproducibility: analysis/statistics/statistics\_results.json; analysis/statistics/count\_inference/count\_inference\_results.json.

## R4-N11 - Independent cylinder transport and the unresolved rare-path test

**EXECUTED, BUT NUMERICAL CONVERGENCE INCOMPLETE where flagged. Do not treat these cases as validated ice-cloud predictions.**

Executed 56 phase/geometry cells: 48 nonvacuum Monte Carlo cases plus 8 analytic vacuum cases. Production used 14.4 million histories in 288 independent batches. A homogeneous finite cylinder spans 14-17 km with 30 km radius; source heights 15, 16, 17, 18 km; observer 550 km and 60 degree circular field. Total vertical particle optical depth takes 0, 0.3, 1, 3, 10, 30, 45.

The scalar GHM bulk phase uses 10 micrometre effective radius and linearly interpolates 330/340 nm optical-model data at the 337.1 numerical coordinate. Its derived  $g$  is 0.7709447; the comparison HG has the same  $g$ . SSA is assumed 1. This is one ice optical model, not measured event microphysics; no polarization, gas absorption, Rayleigh, aerosol, ground or real 3D heterogeneity is present.

Packet flights use exact cylinder intersections, physical path lengths and a nadir next-event estimator with an analytic direct term. Source-proposal importance weights preserve the stated isotropic emission. Production had zero truncated histories, zero negative-delay violations and zero reported 12 ms kernel overflow; maximum weighted energy residual was  $2.91e-15$  per packet. These checks do not certify directional variance convergence.

All 24 nonzero GHM rows remain flagged for nonuniform point-nadir convergence; 10 have estimated fluence standard error above 5%. At source 15 km, total optical depth 10, the production GHM gain  $1.666 \pm 0.118$  changes to  $2.004 \pm 0.099$  with a larger-packet control. A source-cone control gives  $1.805 \pm 0.132$ . These are estimator diagnostics, not confidence bounds on a physical cloud. Rare contributions can escape a small-batch SEM estimate. No physical GHM/HG rise-time bias is inferred.

Two additional exactly matched ideal HG controls were compared to retained CloudScat results. Their  $g=0.87098$ , source 16 km, 12-18 km cylinder and 20 km radius differ from the production grid. Directional gains agree within 0.41 and 0.69 combined batch standard error at overlying optical depth 3 and 10. Timing postprocessing is shared, so this is not an independent timing-estimator validation. GHM and real-ice propagation remain unvalidated.

Retained nonpassing evidence includes a deliberately inadequate 10-scatter cap, packet/proposal/radius sensitivity, and a vacuum-metadata repair. Early code/serialization attempts are logged. Later diagnostic code changes are distinguished from the executed production snapshot; failed controls were not deleted.

$K_{\text{direct}} = \exp(-\tau_{\text{line}})/(4\pi R_0^2)$  perunit aperturearea

$K_{\text{scattered}} = (1/N) \sum_j w_j \omega_j p(\mu_j) \cos(\theta_j) \exp(-\tau_j, \text{obs})/r_j^2$

$\Delta t = (\text{path\_source\_to\_j} + r_j, \text{obs} - R_0)/c$

Angular density: integral over  $4\pi$  steradians  $p(\mu) d\Omega = 1$ . Source and collision angular densities must not be mixed or multiplied twice.

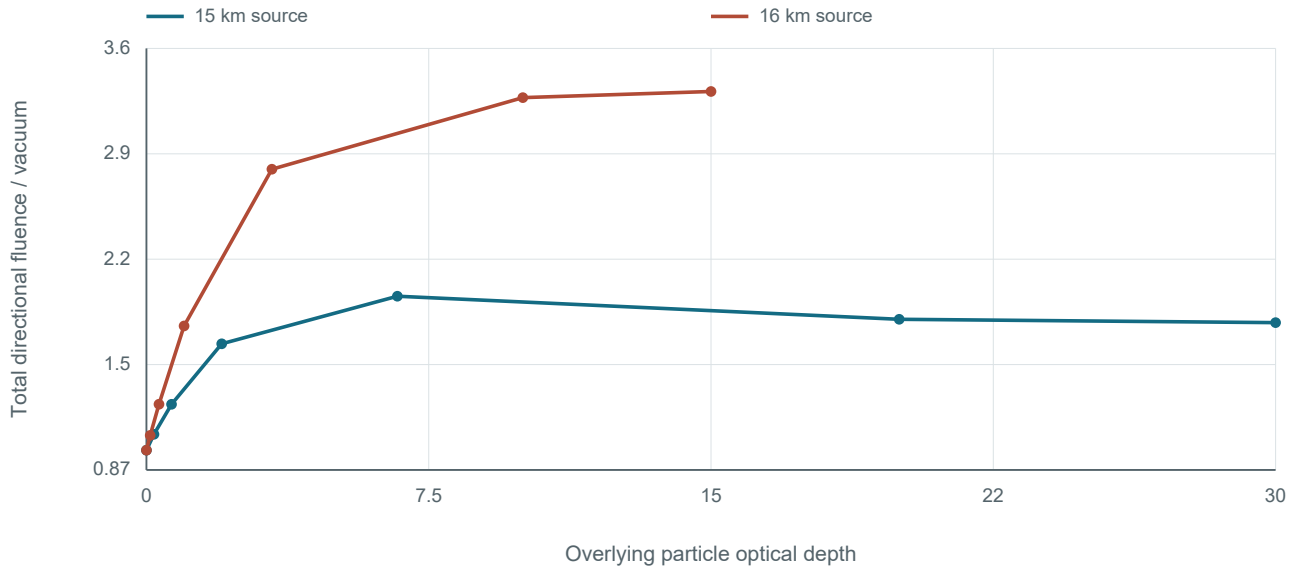
*Production and additional source 15 km, total optical depth 10 controls. +/- values are estimated batch SEM, not physical confidence limits. GHM is not uniformly converged.*

| Phase | Estimator sample      | Histories | Nadir/vacuum gain | Estimated SEM |
|-------|-----------------------|-----------|-------------------|---------------|
| GHM   | production            | 300000    | 1.6661            | 0.11797       |
| GHM   | larger-packet control | 1200000   | 2.0045            | 0.098633      |
| HG    | production            | 300000    | 1.9837            | 0.008725      |
| HG    | larger-packet control | 1200000   | 1.985             | 0.0053223     |
| GHM   | source-cone control   | 1200000   | 1.8051            | 0.13165       |

*Independent-code controls with matched ideal HG and separate geometry:  $g$  0.87098, source 16 km, cloud 12-18 km, radius 20 km.*

| Overhead tau | CloudScat gain | SE       | New gain | SE       | Difference / SE |
|--------------|----------------|----------|----------|----------|-----------------|
| 3            | 2.1996         | 0.016826 | 2.1908   | 0.0134   | 0.40914         |
| 10           | 3.0824         | 0.02763  | 3.1048   | 0.016895 | 0.69377         |

## Conditional HG nadir fluence: two fixed source heights



*Fresh finite-cylinder model, HG  $g=0.77094$ , SSA 1. Source 15/16 km in a 14-17 km cylinder, radius 30 km. Whole-cloud density changes in each curve, so cloud below the source also changes. Exterior gas/aerosol absent; not an overhead-only or real-cloud prediction.*

**Limits.** Conditional model comparison, not a universal transmission curve or inversion. Equal  $g$  does not fix higher phase-function moments. This grid supplies conditional estimates with MC errors; the current GHM rare-path controls do not establish a physical timing bias. Two matched homogeneous-HG controls from the new engine were compared with retained CloudScat outputs and agree within their combined Monte Carlo errors. This independent-code check does not validate tabulated GHM, atmospheric transport or a real-cloud classifier; own analytic tests are labeled separately. The native processed phase grid is assumed. Interpolation, ice habit and size-distribution uncertainties are not represented by MC error. No actual event-brightness population, absolute rate, current calibration, flight noise or rise-time classifier is provided. The tabulated GHM point-nadir rare-path estimator is not uniformly converged. Representative increased-packet and source-proposal controls can differ more than naive finite-batch SEM suggests. Do not infer a physical GHM/HG rise-time bias from unconverged ratios. All original batches and controls are retained. GHM point-nadir rare-path convergence and nonlinear timing uncertainty UV ice habit, roughness, size-distribution and interpolation representativeness Real ice absorption and atmospheric Rayleigh/ozone/aerosol paths 3D cloud structure and source angular/temporal/spectral distribution Observed noisy onset, eventpopulation classifier and flight detection rates Batch SEM is an estimate, not a guaranteed 95% interval. Source and radius controls may share random streams; do not assign independent-difference significance to those comparisons. Aperture transfer has units  $\text{m}^2$  per emitted photon. Multiply by actual aperture area for photon fraction, and only then by appropriate PDE for detected events. Directional gain above 1 is not a photon probability above 1.

Sources: [S097]; [S027]; [S111]

Reproducibility: analysis/cloud/cloud\_results.json; analysis/cloud/cloud\_summary.csv; analysis/cloud/cloud\_timing.csv; analysis/cloud/QA.json; analysis/cloud/validation\_summary.json; analysis/cloud/production/run\_manifest.json; analysis/cloud/validation/cloudscat\_control/comparison.json; analysis/cloud/retained\_failures.json.

## R4-N12 - Conditional transported pulse timing and electronics

Convolved each retained kernel with assumed intrinsic 10-90 rises 30, 80 or 200 us in an exponential-decay source family. Applied no electronics or an ideal first-order 10/50 kHz low-pass. These cutoff frequencies are not ADC sample rates or validated antialias designs.

The table shows only HG examples to avoid presenting unconverged GHM differences as physics. A source 2 km below the modeled top can still have a 30 us input broadened to about 48 us in one HG case. This is a conditional counterexample to a universal geometric-depth threshold, not evidence that an actual deep NBE will always look fast.

Both 10-90 rise and known-model-onset-to-peak are retained separately. Model curves have known onset and no photon noise. Near-window and bin-placement checks have limited scope; they do not validate observed onset, unknown intrinsic pulses or population classification.

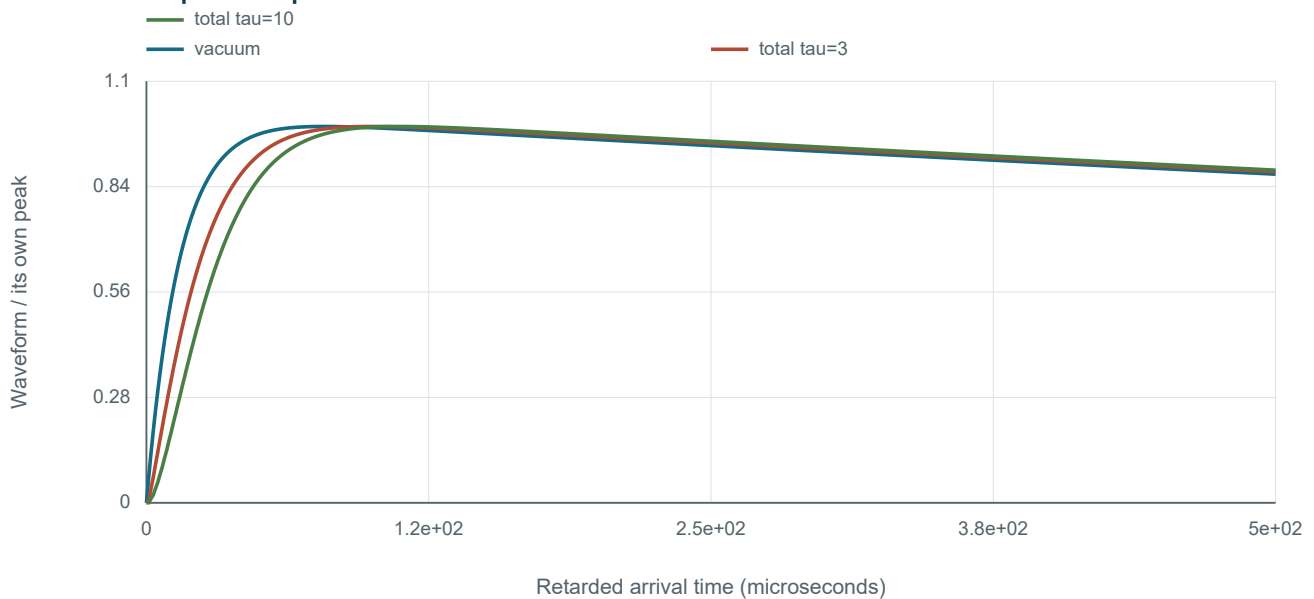
```
source(t)=exp(-t/3 ms)[1-exp(-t/tau_r)]

output = source * cloud_kernel * ideal_lowpass
```

HG g 0.77094, 30 us input 10-90 rise. Gas-free conservative cylinder, not real depth validation.

| Source km | Total tau | Above tau | Gain   | Gain SEM  | Ideal rise us | 10 kHz LP rise us |
|-----------|-----------|-----------|--------|-----------|---------------|-------------------|
| 15        | 0         | 0         | 1      | 0         | 30            | 48.036            |
| 15        | 3         | 2         | 1.6798 | 0.0085844 | 41.617        | 56.495            |
| 15        | 10        | 6.6667    | 1.9837 | 0.008725  | 48.227        | 61.542            |
| 15        | 30        | 20        | 1.8364 | 0.0043262 | 71.938        | 82.137            |
| 16        | 0         | 0         | 1      | 0         | 30            | 48.036            |
| 16        | 3         | 1         | 1.7938 | 0.0090274 | 42.948        | 57.636            |
| 16        | 10        | 3.3333    | 2.7951 | 0.016188  | 47.674        | 61.132            |
| 16        | 30        | 10        | 3.2524 | 0.015135  | 64.721        | 76.127            |
| 17        | 3         | 0         | 1.4624 | 0.0014462 | 43.382        | 58.083            |
| 17        | 10        | 0         | 2.0285 | 0.0041485 | 46.469        | 60.382            |
| 17        | 30        | 0         | 2.4562 | 0.004879  | 46.217        | 61.239            |
| 18        | 3         | 0         | 1.445  | 0.0030387 | 54.533        | 67.652            |
| 18        | 10        | 0         | 1.9828 | 0.005117  | 58.213        | 70.222            |
| 18        | 30        | 0         | 2.4114 | 0.007451  | 58.59         | 70.581            |

#### Conditional HG pulse shape for a 30 us intrinsic rise



Shape only: each curve is normalized to its own output peak. The horizontal coordinate subtracts the direct source-observer flight time  $R0/c$ ; it retains the source onset and excess-path delay. This view does not compare amplitudes. First 0.5 ms shown; timing metrics use the recorded longer window. Conditional homogeneous HG cloud, gas-free conservative transport and an assumed source pulse; no observed source-depth classification is implied.

**Limits.** HG is a comparison phase model, not an event-specific ice measurement. GHM timing remains numerically unconverged. Assumed source decay 3 ms is not a universal observed duration. Output normalized to its own peak hides amplitude differences intentionally. Known-model onset, 10-90 rise, arrival quantiles and noisy inferred onset are different quantities. No detector dead time, correlated noise, uncertain baseline or sampling-phase likelihood included in this transport convolution.

Sources: [S097]

Reproducibility: analysis/cloud/cloud\_results.json; analysis/cloud/cloud\_timing.csv; analysis/cloud/timing\_metrics.py; analysis/cloud/QA.json.

# Minimum remaining validation program

Choose a realizable optical phase-space layout and receiver chain, including field, filter, area, dynamic range, power, thermal and safety states.

Measure traceable 337/777 spectral-angular photon response, noise, time response, count losses and recovery on the full assembled head.

Test source/cloud and artifact alternatives using calibrated pulses and independently labeled physical observations; report both accepted fractions and errors.

Propagate selected-part radiation and contamination effects into end-of-life sensitivity, and validate calibration drift paths.

Acquire a joint faint-source/scene/exposure sample with non-detections, versioned selection and valid observing live time before predicting useful polar yield.

## Terms and units

*Definitions retain their reference plane and convention.*

| Term             | Meaning                                                                                            |
|------------------|----------------------------------------------------------------------------------------------------|
| Photon           | One packet of light energy.                                                                        |
| PDE              | Probability that an incident photon produces a useful detected event, with reference plane stated. |
| QE               | Quantum efficiency at a material/device stage; not automatically complete instrument PDE.          |
| Irradiance       | Power per unit receiving area.                                                                     |
| Radiance         | Power per projected area per solid angle; add pernm for spectral radiance.                         |
| Fluence          | Time-integrated energy or photon number per receiving area.                                        |
| Optical depth    | Dimensionless accumulated extinction along a path.                                                 |
| Phase function   | Probability density for scattering into a direction.                                               |
| Etendue          | Optical area-and-angular acceptance, including refractive index.                                   |
| NEP              | Noise-equivalent optical power under a stated spectral/bandwidth convention.                       |
| DCR              | Dark-count rate at specified temperature, bias and threshold.                                      |
| ENBW             | Equivalent noise bandwidth of the complete filter/estimator.                                       |
| Dead time        | Time-dependent lost-event acceptance following detection.                                          |
| Confidence limit | A bound from a procedure with stated repeated-sampling coverage.                                   |
| TID / DDD / SEE  | Ionizing dose, displacement damage and individual radiation-induced events.                        |
| E/N              | Electric field divided by neutral-gas number density; relevant to electron energies.               |
| Current moment   | A source quantity involving current and spatial extent; not identical to current.                  |

# Sources, access and applicability

116curated cited records include papers, related datasets, official technical documentation and manufacturer sheets. They are not 116independent studies or observing cohorts. Each record is used only for its stated limited claim; access and rights restrictions remain explicit.

Original URLs and DOIs are clickable. Record-specific access statements distinguish inspected full text, selected pages, manufacturer sheets, data/interface audits and limited-access leads. No restricted GLIMS/RAIDS raw data are reproduced. Where no specific license was established, the entry supplies paraphrased findings and an original link only; it does not grant raw-data redistribution rights. Related versions and data products are not independent observing cohorts.

## [S001] Introduction to TRE x-ATM V 2.0: A Versatile Model of Auroral Transport and Its Effects in the Ionosphere

Attribution/date: 2026

Original URL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2026EA005013>

DOI: [10.1029/2026EA005013](https://doi.org/10.1029/2026EA005013)

Locator: Published model description/optical-output claims; API availability is separately audited in BG 021. No exact 337 numerical result taken from this source..

Access: Open publisher methods, comparison table, inversion tests, uncertainty table and availability inspected

Applicability limits: Model scenario output requires particle inputs and is not a Kp-binned observational climatology. Ground atmospheric corrections cannot be applied blindly to upward/nadir geometry.

## [S002] LIME: Lunar Irradiance Model of ESA

Original URL: <https://acp.copernicus.org/articles/24/3649/2024/index.html>

DOI: [10.5194/acp-24-3649-2024](https://doi.org/10.5194/acp-24-3649-2024)

Locator: LIME instrument/model band coverage and validation; actual v 2 observed-wavelength archive inspected separately in campaign..

Access: Open primary methods and instrument bands inspected

Applicability limits: An interpolated or extrapolated 337 nm prediction needs an independent UV uncertainty budget; the actual photometer has no 337 nm band.

## [S003] Measurements of absolute, SI-traceable lunar irradiance with air-LUSI

Original URL:

<https://www.nist.gov/publications/measurements-absolute-si-traceable-lunar-irradiance-airborne-lunar-spectral-irradiance>

DOI: [10.1088/1681-7575/ac64dc](https://doi.org/10.1088/1681-7575/ac64dc)

Locator: Abstract and wavelength-dependent uncertainty results: measured 350-980 nm; <=1% demonstrated 450-970 nm..

Access: NIST primary abstract and instrument/uncertainty summary inspected

Applicability limits: Neither the nominal instrument range nor the stated lowest uncertainty validates 337 nm calibration.

## [S004] USGS Lunar Calibration: current mission considerations and uncertainty

Original URL: <https://www.usgs.gov/calval/lunar-calibration>

Locator: Official page mission-considerations and uncertainty discussion; lunar viewing/opposition constraints..

Access: Official full page inspected

Applicability limits: These are general mission/calibration characteristics, not a calibrated 337 nm lunar irradiance or a free operational resource.

## [S005] The spectral irradiance of the Moon

Original URL: <https://pubs.usgs.gov/publication/70029564>

DOI: [10.1086/430185](https://doi.org/10.1086/430185)

Locator: ROLO observed wavelength bands and empirical phase/libration model; lowest fitted band about 350 nm..

Access: Primary USGS publication record and abstract inspected; original paper discovered

Applicability limits: 337 nm lies outside the measured wavelength range; absolute accuracy and fit residual are different quantities.

## [S006] TEMPO at Night

Original URL: <https://ntrs.nasa.gov/citations/20260001290>

DOI: [10.1029/2024EA004157](https://doi.org/10.1029/2024EA004157)

Locator: PDF§2.1, 2.4, 3, 4.2, 4.3, 4.6, Open Research; NASA metadata publication date 2025-10-01, acquired 2026-02-10.

Access: NASA 27 pageaccepted manuscript: instrument, noise, observingwindows, moon, aurora, lightning and availability inspected; publisher metadata compared

Applicability limits: Do not treat limb examples or visible moon examples as a polar nadir 4 nm 337 climatology. Need raw twilightradiance, postprocessing, errorcovariance and filterfolding. TEMPO does not cover 777.4 nm.

#### **[S007] A Ground-Based Instrument Suite for Integrated High-Time Resolution Measurements of Pulsating Aurora With Arase**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023JA031527>

DOI: [10.1029/2023JA031527](https://doi.org/10.1029/2023JA031527)

Locator: §2.2 and Table 1; §3.1, Figure 5.

Access: Primary full instrument and calibration sections inspected

Applicability limits: The described bands are 427.8, 844.6, 777.4 and 650-700 nm, not a measured 337 nm profile. Illustrates calibration/energy-ratio degeneracy, not 30μspolar 337 climatology.

#### **[S008] TRE x-ATM V 2: current public API capability audit**

OriginalURL: <https://api.phys.ucalgary.ca/docs>

DOI: [10.1029/2026EA005013](https://doi.org/10.1029/2026EA005013)

Locator: Current public Open API response schema and optical output fields, archived during campaign; arbitrary 337/777 outputs not declared..

Access: Actual Open API document fetched 2026-10-21 T 22: 28: 53 Z, 91408 bytes, SHA 256 d 38533 aa 0 dc 168 a 5458 c 2617 df 4 bc 3 b 1 c 906 dff 46 a 9504 ec 0 b 6 d 23 f 52 c 4 7e3 dd

Applicability limits: A paper-level capability is not proof of a callable 337/777 API. Do not send invented flags or relabel 427.8 as 337. This audit corrects the earlier broad BG 006 API availability implication; source code/access or another model must be checked before running 337/777 scenarios.

#### **[S009] GLOW official atmospheric-emission model source and published auroral example**

OriginalURL: <https://github.com/NCAR/GLOW>

Locator: model\_code/NCAR\_GLOW\_Glowlicense.txt; model\_code/NCAR\_GLOW\_in.basic.aur; reference\_numbers\_audit.json.

Access: Pinned source, license, example inputs and output inspected; rounded example integrated locally. No compiler/model execution.

Applicability limits: An imposed precipitation scenario is not a measured moderate-Kp radiance or orbital distribution. Academic research license retained; no fresh atmospheric model run claimed.

#### **[S010] Observations of the moon by GOME: radiometric calibration and lunar albedo**

OriginalURL: <https://opg.optica.org/ao/abstract.cfm?uri=ao-37-33-7832>

DOI: [10.1364/AO.37.007832](https://doi.org/10.1364/AO.37.007832)

Locator: Abstract; Table 1.

Access: Primary abstract and Table 1 inspected. Full text and figures are subscription restricted.

Applicability limits: Not justified to say UV lunar measurements do not exist. Actual 337 nm albedo, geometry and error budget have not been extracted from this restricted full text.

#### **[S011] The 1997 reference of diffuse night sky brightness: ultraviolet zodiacal table**

OriginalURL: <https://aas.aanda.org/articles/aas/pdf/1998/01/ds1449.pdf>

DOI: [10.1051/aas:1998105](https://doi.org/10.1051/aas:1998105)

Locator: Table 19; Section 8.4; reference\_numbers\_audit.json.

Access: Primary publisher cached Section 8.4/Table 19 recovered. Direct PDF access 403/timeout, not a fully read local PDF.

Applicability limits: Interpolation choice is not an uncertainty interval. Incident celestial radiance must be integrated over cloud illumination and BRDF; it is not an Earth-filled nadir background.

#### **[S012] RAIDS public calibrated near-UV archive and mission README**

OriginalURL: <https://spdf.gsfc.nasa.gov/pub/data/raids/>

Locator: round 04/raids\_readme.pdf, pp 1--2; round 04/raids\_nuv\_qualification.json; round 04/raids\_nuv\_sample\_header.json.

Access: README, Newsletter 6, directory listings and one small public Net CDF inspected; header and geometry audit saved.

Applicability limits: Single commissioning-day limb sample is neither nadir cloud nor polar climatology. No radiance numbers exported. README requests PI authorization and advance draft review before publication/presentation. Private qualification only; no external contact made.

#### **[S013] Low-latitude nightglow pseudo-continuum 300--1800 nm**

OriginalURL: <https://acp.copernicus.org/articles/24/1143/2024/>

DOI: [10.5194/acp-24-1143-2024](https://doi.org/10.5194/acp-24-1143-2024)

Locator: Section 2; Section 3; Data availability; round 05/Noll et al.(2024)\_primary.xml.

Access: Primary instrument, calibration, continuum-separation, conclusion and data-availability sections inspected; full XML retained.

Applicability limits: Low-latitude ground data need extinction/sky-component separation and satellite illumination geometry. A continuum-only spectrum omits structured O2 bands and must not replace total 337 background or double-count a complete sky model.

#### **[S014] TSIS-1 Hybrid Solar Reference Spectrum version 2 and uncertainty interpretation**

OriginalURL: [https://lasp.colorado.edu/lisird/data/tsis1\\_hsrs/](https://lasp.colorado.edu/lisird/data/tsis1_hsrs/)

Locator: round 05/HSRS\_p 1 nm\_v 2.nc; round 05/spectral\_geometry\_audit.json; Coddington 2021 Section 4.2.

Access: Official variants/metadata inspected; 2.44 MB v 2 HDF 5 file retrieved/hashed and solar-only filter integrations executed; 2021 primary uncertainty text inspected.

Applicability limits: Sunlight is not nightside or lunar irradiance. No absolute Moon flux was derived. 1.3% UV broadband uncertainty is not an independent error for every fine spectral pixel; individual line discrepancies can be larger.

#### **[S015] Alternative hyperspectral Moon phase-reddening model: original LESSSR report**

OriginalURL: [https://www-cdn.eumetsat.int/files/2021-02/ESS-AMM-RP-001-Rev5\\_LunarModel\\_FINAL\\_EUMETSATwebsite.pdf](https://www-cdn.eumetsat.int/files/2021-02/ESS-AMM-RP-001-Rev5_LunarModel_FINAL_EUMETSATwebsite.pdf)

Locator: Sections 5.4, 6.3--6.6, 7.2.

Access: Primary 34 page 2019 report selected calibration/model/validation sections inspected.

Applicability limits: No machine-readable coefficient set retrieved yet. UV calibration/polarization features and GOME 2 comparison differences limit an unqualified high-accuracy 337 claim.

#### **[S016] Updated LESSSR lunar model study completed 2024, public overview 2025**

OriginalURL: <https://www.eumetsat.int/enhancing-eumetsat-lunar-extended-satellite-simulation-reflectance-model>

Locator: Overview; Table 1; Data resources.

Access: Official full overview, model-range descriptions and data-resources section inspected.

Applicability limits: LCS service scope starts 350 nm and the discussed base-function fit grid starts 350 nm, despite broader model range elsewhere on the same page. Actual 337 nmv 2 coefficients/support need clarification. No claim that coefficients are publicly downloadable or that we ran this model. No external contact made.

#### **[S017] Actual Noll et al.(2024) mean continuum spectral dataset**

OriginalURL: <https://zenodo.org/records/8335837>

DOI: [10.5194/acp-24-1143-2024](https://doi.org/10.5194/acp-24-1143-2024)

Locator: Zenodo 8335837 mean continuum table, 0.5 nm grid; processed selection/line-removal conventions in Noll et al.(2024)..

Access: Verifiedranged ZIP centraldirectory and 6 smallmembers CRC 32/SHA checked; whole 151 MBZIP notdownloaded. Actualmean spectrum and README inspected. CC BY 4.0.

Applicability limits: The extracted pseudo-continuum includes many unresolved O2 ultraviolet bands; strong resolved lines were removed. It is not the total polar 337 or 777 nm sky background. Broad extraction windows and a 0.5 nm grid do not establish a sub-nanometre filter optimum.

#### **[S018] Bianchi(2024) Gaia-based direct and diffuse starlight model with actual sky cube**

OriginalURL: <https://cdsarc.cds.unistra.fr/viz-bin/cat/J/A+A/691/A330>

DOI: [10.1051/0004-6361/202451086](https://doi.org/10.1051/0004-6361/202451086)

Locator: CDS J/A+A/691/A 330; 99-bin mean intensity table and celestial NESTED Nside64 direct+diffuse sky cube..

Access: Fullauthorarxiv 1 HTML inspected, final CDSR ead Me/99 row Jtable/15.63 MB gzip 49152 x 99 sky cube downloaded andhashed. Finalpublisher directfetch 403; indexedfinaldataavailabilityqualifies CDS route.

Applicability limits: The ultraviolet extension uses stellar-atmosphere/extinction models and an empirical diffuse-light fit, rather than a direct 4 nm measurement at 337 nm. The roughly 13 nm wavelength bracket cannot resolve 4 nm spectral structure. Interpolating it does not provide a new pixel covariance or confidence interval.

#### [S019] Rovibronic molecular line list for the N2(C 3 Pi\_u-B 3 Pi\_g) second positive system

OriginalURL: <https://www.osti.gov/servlets/purl/2311352>

DOI: [10.1016/j.jqsrt.2023.108809](https://doi.org/10.1016/j.jqsrt.2023.108809)

Locator: section 2, Eqs 2-3; section 3; Figures 4-6; Tables 1-2; section 4.

Access: Author preprint dated 2023-11-01; all 7 pages text inspected, Figure 6 p 5 visually inspected. Published JQSRT 312(2024)108809.

Conditions/scope: Spectroscopic line-position/strength model validated by author against experimental FTS and SPECAIR under stated laboratory conditions. Not an NBE radiometric calibration.

Applicability limits: Official current ExoMol metadata identifies the 20240705 C-B extension. Public .states/ERJ.trans requests timed out here: this is a local access failure, not global unavailability. Zenodo 5717009 contains the older 20190916 archive, created and modified in 2021; it does not include the Jans et al. 2024 C-B extension.

#### [S020] The Spectrum of Molecular Nitrogen

OriginalURL: <https://srdb.nist.gov/JPCRD/jpcrd93.pdf>

DOI: [10.1063/1.555546](https://doi.org/10.1063/1.555546)

Locator: section 3.13 printedp 139; Table 29 printedp 226; Appendix A(9) printedp 307.

Access: 195-page scanned official NIST PDF retrieved with SHA 256; selected printedp 113, 115, 117, 123, 139, 226, 306, 307 visually inspected. Not all 195 pages read.

Conditions/scope: Critical spectroscopic compilation; historical source bandheads, not event-specific spectrum.

Applicability limits: A bandhead is not the band centroid or a monochromatic representation. Air/vacuum wavelength conversion does not describe a physical coating passband change in vacuum. Both require explicit metadata.

#### [S021] Moose / original Massive OES N2CB numericaldata and query-interface audit

OriginalURL: <https://github.com/AntoineTUE/Moose>

Locator: Pinned Moose/original Massive OES data/query audit; lower-state link, energy/J and coordinate checks. These are conditional reconstructions, not an accepted NBE spectrum..

Access: Actual SQL ite 11225088 B and selected sourcefiles retrieved andhashverified. No software installed or outsidepackagecode executed. Own SQL ite/arithmetic audits executed.

Conditions/scope: Numerical spectroscopy implementation and diagnostic, not a measurement.

Applicability limits: The attempted initial v0-v0 filter fold was invalidated; no physical capture fractions from it are retained. Later candidate mappings are conditional diagnostics. Population/spin weights, original line positions and Einstein A values still require independent primary comparison.

#### [S022] Standard-air wavelength convention and refractivity arithmetic

OriginalURL: <https://emtoolbox.nist.gov/Wavelength/Documentation.asp>

Locator: NIST refractive-index-of-air/wavelength documentation; standard-air coordinate conversion, not a physical filter-vacuum shift..

Access: Official NIST documentation sections IV, VI, VII and Jones 1981Eq 1/introduction printedp 27 inspected throughbrowser. Wholevolume notdownloaded/read.

Conditions/scope: Ownstandardaircoordinatecalculation using publisheddispersion formula; not measured anvil refractivity.

Applicability limits: No nominal wavelength was silently changed in the frozen calculations. NIST discusses air-index models over 300-1700 nm with condition-dependent uncertainty. A nominal dry-air conversion does not certify old table accuracy or an event band centroid.

#### [S023] Orbital broad UV background cross-check and response-positivity bound

OriginalURL: <https://data.mendeley.com/datasets/57fmn7rh4n/4>

Locator: Dataset wavelength\_response.txt and Europe\_North Africa\_map.txt; Mini-EUSO broad-band response/positivity audit, not a 4 nm measurement..

Access: Cross-stream source package: exact ten-source list/access levels in sourcebranchprimaryreview, not a single independent dataset.

Conditions/scope: Measured broadbandcounts plus calibrationmodels and ownconditionalbound; not measured 4 nm 337 radiance.

Applicability limits: This is not an exposure-weighted polar background distribution or a faint-event rate. Scene conditions, selection, trimming and modal-statistic qualifications must accompany its measurements.

**[S024] Mesoscale structure of flickering aurora from wide-field high-speed imaging**

OriginalURL: <https://angeo.copernicus.org/articles/44/959/2026/>

DOI: [10.5194/angeo-44-959-2026](https://doi.org/10.5194/angeo-44-959-2026)

Locator: sections 2-3; Figure 1; Appendices A, C; Dataavailability.

Access: Primary full HTML methods, results, appendices and data availability inspected; XML/metadata access separate in receipt. No raw image/video download.

Conditions/scope: One unfiltered high-speed ground-observation event; spatial mapping assumes 110 km emission height.

Applicability limits: It supplies neither absolute 337 nm radiance nor a microsecond power spectrum or Kp-conditioned population. Neighboring patches are correlated; independent-cell averaging proportional to  $1/\sqrt{N}$  cannot be assumed.

**[S025] Some photometer results obtained on the NASA 1969 Airborne Auroral Expedition**

Attribution/date: 1971

OriginalURL: <https://ntrs.nasa.gov/citations/19720005652>

Locator: NASA-CR-124719, PDF pp 4-5 filter/calibration; pp 8, 11 selected night observations; page 67 bright sample is midday..

Access: Original 77 page public NASA PDF locally retained; summary/calibration/filter table and selected night/day tables visually verified.

Conditions/scope: Measured filter-channel equivalent brightness, dark-current corrected; not spectrally pure N<sub>2</sub>(0, 0).

Applicability limits: Airglow, starlight, moonlight and other features were not removed; the weak-end accuracy at a few tens of Rayleigh is described qualitatively. The inspected 1971 summary does not expose a full filter curve, equivalent bandwidth, formal uncertainty, per-wavelength timestamps or complete zenith extinction correction.

Rights/access: NTRS metadata: Work of USG ov, Public Use Permitted; private working copy.

**[S026] Coordinated analysis of various auroral measurements made during NASA 1968 and 1969 airborne auroral expeditions, chapter III**

Attribution/date: 1976

OriginalURL: <https://ntrs.nasa.gov/citations/19760014714>

DOI: [10.1029/JA081i034p06046](https://doi.org/10.1029/JA081i034p06046)

Locator: NASA-CR-146857, chapter III; Table 2 printed p 47/PDF 57; calibration printed pp 38-40, 46-50..

Access: Original 102 page public NASA PDF locally retained; printed pp 38-40, 46-50, 54-55, 60 inspected; key calibration/table pages visually verified.

Conditions/scope: Selected auroral spectrum, blend-separated band area and atmosphere-corrected absolute calibration. Chapter title/authors match journal lead; journal full text not obtained for byte/content identity. Not independent observing campaign.

Applicability limits: N<sub>2</sub>(C) band intensity is not a measured spectral radiance per nanometre or an actual 4 nm filter fold. A two-minute selected zenith spectrum is not a wide-field orbital distribution or a Kp climatology.

**[S027] Spectrally consistent scattering, absorption, and polarization properties of atmospheric ice crystals at wavelengths from 0.2 to 100µm**

Attribution/date: P. Yang, L. Bi, B. A. Baum, K.-N. Liou, G. W. Kattawar, M. I. Mishchenko, B. Cole 2013

OriginalURL: <https://www.giss.nasa.gov/pubs/abs/ya07100h.html>

DOI: [10.1175/JAS-D-12-039.1](https://doi.org/10.1175/JAS-D-12-039.1)

Locator: NASA GISS publication abstract; NASA abstract last sentence.

Access: author\_institution\_abstract\_only; publisher\_fulltext\_pending

**[S028] MCAR aTS developer documentation version 0.10 and change log 0.10.3**

Attribution/date: documentation undated; latest listed release 2016-09-06

OriginalURL: <https://sites.google.com/site/mcarats/>

Locator: Introduction; job namelist Src\_mtype Src\_apsize; initialization Rad\_mplen=3, Rad\_ntp, Rad\_tpmin/tpmax; initialization namelist Rad\_mplen and Rad\_tpmin/tpmax; initialization Wld\_moptim and Sca\_qtymax; job Rad\_mrproj and Rad\_difr 0/1; change log 0.10.2; change log 2016-09-06; introduction.

Access: developer\_documentation\_sections\_examined; code\_not\_downloaded\_or\_run

**[S029] McRALI: a Monte Carlo high-spectral-resolution lidar and Doppler radar simulator for three-dimensional cloudy atmosphere remote sensing**

Attribution/date: 2021-01-12

OriginalURL: <https://amt.copernicus.org/articles/14/199/2021/amt-14-199-2021.html>

DOI: [10.5194/amt-14-199-2021](https://doi.org/10.5194/amt-14-199-2021)

Locator: sections 2.1-2.3 and code-availability statement; methods and conclusions; our applicability assessment.

Access: publisher\_full\_HTML; methods 2.1-2.3, conclusion and code availability examined

#### **[S030] MSCART developer documentation**

Attribution/date: documentation build2025-05-06

OriginalURL: <https://intersharp.gitlab.io/mscart-docs/page/index.html>

Locator: feature table; lidar case; input Rad/PR ad/Sca settings.

Access: developer\_features, input, case, and\_reference pages read

#### **[S031] SMART-G developer README, changelog and license**

Attribution/date: versions2.0.0 on2026-09-30,2.0.1 on2026-10-02,2.0.2 on2026-10-08

OriginalURL: <https://github.com/hygeos/smartg>

Locator: README installation/features; changelog 2.0; changelog 2.0.0-2.0.2; LICENSE/README.

Access: complete developer README and selected changelog entries read

#### **[S032] On Rayleigh Optical Depth Calculations**

Attribution/date: Barry A. Bodhaine, Norman B. Wood, Ellsworth G. Dutton, James R. Slusser 1999-11-01

OriginalURL: [https://web.gps.caltech.edu/~vijay/Papers/Rayleigh\\_Scattering/Bodhaine-et-al-99.pdf](https://web.gps.caltech.edu/~vijay/Papers/Rayleigh_Scattering/Bodhaine-et-al-99.pdf)

DOI: [10.1175/1520-0426\(1999\)016<1854:ORODC>2.0.CO;2](https://doi.org/10.1175/1520-0426(1999)016<1854:ORODC>2.0.CO;2)

Locator: sections 1-2, equations 2, 5-6, 9; section 3; Table 2; equation 8.

Access: author/institution\_hosted\_full\_PDF; all 8 pages extracted, sections 1-4 read closely

#### **[S033] mitransient volumetric transient integrator and Mitsuba 3 phase/emitter interfaces**

Attribution/date: living developer documentation accessed2026-10-21

OriginalURL: <https://github.com/diegoroyo/mitransient>

Locator: developer integrator/film docs; phase/emitter docs; our applicability assessment; mitransient\_volume\_interface\_audit.json; lines 216-239, 261, 334.

Access: Official docs and source transient\_prbvolpath.py read; no renderer installed or executed.

#### **[S034] U S Standard Atmosphere 1976 deeper primary scan and clear-air audit**

Attribution/date: 1976-10-01

OriginalURL: <https://ntrs.nasa.gov/api/citations/19770009539/downloads/19770009539.pdf>

Locator: printed 2-3 Tables 2-4, printed 36-39 Tables 18-19; Rayleigh\_standard\_vs\_frozen\_337\_audit.json; USSA 1976\_ozone\_above\_source\_audit.json.

Access: Original 243 pagegovernment PDF privatelyretained; selectedprinted 2-3, 36-39 visuallyread. Scanned OCR ispoor. NASA 2005 Appendix A independentlycrosschecksformulas.

#### **[S035] Exploiting breakdown of the similarity relation for diffuse light transport simultaneous retrieval of scattering anisotropy and diffusion constant**

Attribution/date: T. Svensson, R. Savo, E. Alerstam, K. Vynck, M. Burrese, D. S. Wiersma 2013-02-08publisheronline;2013-02-15issue

OriginalURL: <https://arxiv.org/abs/1211.6690>

DOI: [10.1364/OL.38.000437](https://doi.org/10.1364/OL.38.000437)

Locator: preprintpp 2-3, figures 2-3; preprintp 2, figure 1 anddiscussionp 3; ourinterpretationofcontrolledexperiment.

Access: Primary 4-pageauthorpreprintmaintextread, publisherabstractverified. Nojournalpaywallbypass. Preprint PDF dateline 2018-09-03 differsfromv 1 submissionhistory; version URL andhashretained.

#### **[S036] Optical constants of ice from the ultraviolet to the microwave A revised compilation deeper baseline audit**

Attribution/date: Stephen G. Warren, Richard E. Brandt 2008-07-31

OriginalURL: [https://atmos.uw.edu/ice\\_optical\\_constants/Warren\\_and\\_Brandt\\_2008.pdf](https://atmos.uw.edu/ice_optical_constants/Warren_and_Brandt_2008.pdf)

DOI: [10.1029/2007JD009744](https://doi.org/10.1029/2007JD009744)

Locator: section 2 paragraphs 6-7, p 2; section 7 paragraph 34, p 7; frozenphase\_validation.jsonread-onlyand GHM\_ice\_absorption\_provenance\_followup.json.

Access: Primaryauthor 10-page PDF sections 1, 2, 7 read; privatelyretained 644261 Bwith SHA 256.  
Originalunderlyingexperimentsnotallreviewed.

**[S037] Smoke of extreme Australian bushfires observed in the stratosphere over Punta Arenas, Chile, in January 2020: optical thickness, lidar ratios, and depolarization ratios at 355 and 532 nm**

Attribution/date: Kevin Ohneiser et al. 2020-07-10

OriginalURL: <https://acp.copernicus.org/articles/20/8003/2020/>

DOI: 10.5194/acp-20-8003-2020

Locator: table 1 row 10 Jan 2020, 02: 25-04: 20 UTC; table 1 and sections 3-4.

Access: Selected primary methods/results and table 1 read; primary XML retained privately. Actual OASIS table namespace parsed.

**[S038] libRadtran current documentation and public MYSTIC availability**

Attribution/date: libRadtran developers Live documentation, last modified2024-12-22

OriginalURL: <https://www.libradtran.org/doku.php?id=documentation>

Locator: documentation lines 30 and 49-58; basic\_usage MYSTIC section.

Access: Current official documentation and basic-usage pages read; no software installed/run. Manual link advertises 2.0.6, not yet privately retrieved.

**[S039] Multi-wavelength calibration procedure for the Pierre Auger Observatory fluorescence detectors**

OriginalURL: <https://arxiv.org/pdf/0811.1518>

DOI: 10.1016/j.astropartphys.2009.02.009

Locator: sections 4.1-5.2; Table 2; Eq.(2).

Access: Full author manuscript v 2 and primary author-institution published-version metadata; Astroparticle Physics 31 (2009) 305-311.

Applicability limits: A bright calibrated photodiode transfer is useful even if a PIN detector is too noisy for the faint science signal. This is not a 1% absolute 337 nm standard or a 30  $\mu$ s pulse simulator. Whole-path and piecewise component calibration can differ; narrow mission filters need finer wavelength sampling than this study.

**[S040] CALSPEC stellar spectrophotometric standards and current Vega spectrum**

OriginalURL: <https://www.stsci.edu/hst/instrumentation/reference-data-for-calibration-and-tools/astronomical-catalogs/calspec>

Locator: CALSPEC composition/cautions/history; FITS primary HISTORY and SCI BINTABLE header.

Access: Official STS cl page and primary FITS file retrieved; header verified, 288000 bytes, SHA 256 7201cd8566d53d384430c3d5fd2ae8d8122e9 a7f765711748b49336f63237672.

Applicability limits: A stellar standard exists at 337 nm, but this does not give a complete 1% receiver calibration. Actual response, backgrounds and pointing remain required. The private Vega fold is an ideal-band photon-statistics illustration; spectral resolution is about 0.55 nm near 337 and 0.98 nm near 777, not a line-resolved nitrogen/oxygen reference.

**[S041] Optics and Opto-Electronics Laboratory**

OriginalURL: <https://technology.esa.int/lab/optics-and-opto-electronics-laboratory>

Locator: Optical characterization; detector calibration; air-vacuum coating spectral shift.

Access: Official current ESA facility description

Applicability limits: Specific receiver geometry, low-light pulse bandwidth, uncertainty and access terms need confirmation. Coverage of a wavelength is not a demonstrated complete instrument calibration uncertainty.

**[S042] Calibration and Characterization of the Ice Cube Photomultiplier Tube**

OriginalURL: <https://arxiv.org/pdf/1002.2442>

DOI: 10.1016/j.nima.2010.03.102

Locator: sections 9.1-9.3, pp.22-27; Table 3; section 11, pp.34-35.

Access: Primary author preprint; journal 2010; automated preprint footer has an inconsistent 2024 date

Conditions/scope: Hamamatsu R 7081-02, 10-inch PMT; laboratory measurements, not a Cube Sat PMT

Applicability limits: Results depend on detector geometry, bias, threshold and individual sample; they are not universal PMT values. The 4 ns nitrogen laser is useful for impulse calibration but does not reproduce the desired 3 ms envelope.

**[S043] Sensitivity degradation of ISUAL instruments and its impact on observations**

OriginalURL: <https://sprite.phys.ncku.edu.tw/joomla3/images/stories/useruploads/airosprey/1-4.pdf>

DOI: [10.3319/TAO.2011.06.20.01\(AA\)](https://doi.org/10.3319/TAO.2011.06.20.01(AA))

Locator: sections 2-2.1; printed pp.73, 75-76; Tables 1-2.

Access: Full primary team-hosted published article, 2012; 7024538-byte PDF read in memory, extracted text/provenance saved. Shared source with alternative\_check; complementary calibration-path qualification.

Applicability limits: These are internal mainly-red LED response trends after preflight voltage-gain correction, not direct 337 nm PDE aging or isolated radiation damage. LED stability is assumed from duty, dose and temperature arguments. The reference pathway does not establish science-wavelength throughput stability. The source-population stream independently retrieved the same paper; cross-link its record rather than count this as independent evidence.

#### **[S044] Predicting electrically generated hydrogen oxides from ultraviolet radiation emissions**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2026JD046463?af=R>

DOI: [10.1029/2026JD046463](https://doi.org/10.1029/2026JD046463)

Locator: sections 2.1, 2.2.1, 2.3.2, 2.4.3, 3.3; Table 1; Figure S16 description.

Access: Primary publisher full HTML verified through af=R; direct full URL initially failed. Supporting DOCX returned 403. Official data recovered independently.

Applicability limits: No instantaneous 337 peak-current law is determined; source conditions differ from 15-18 km NBEs. The corona PMT's 340 nm/12 nm filter and a 10 nm spectral sum are not a 4 nm 337.1 nm receiver.

#### **[S045] LEDD1B and T-Cube LED drivers**

OriginalURL: [https://www.thorlabs.us/NewGroupPage9\\_PF.cfm?ObjectGroup\\_ID=6148](https://www.thorlabs.us/NewGroupPage9_PF.cfm?ObjectGroup_ID=6148)

Locator: LEDD1B modulation specifications table and notes.

Access: Official manufacturer specification page.

Applicability limits: This driver is not automatically a 30  $\mu$ s optical-rise simulator. Current step, LED load, bias and optical tail must be measured. The driver waveform is not a calibrated optical waveform; use a fast reference detector and verify the complete attenuator/sphere path.

#### **[S046] Mounted LEDs: M340L5**

OriginalURL: [https://www.thorlabs.com/newgrouppage9.cfm?objectgroup\\_id=2692](https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=2692)

Locator: M340L5 table row; operating conditions.

Access: Official current manufacturer table.

Applicability limits: It can supply light through a 337 nm passband, but this is not monochromatic 337.1 nm emission. Spectral overlap, attenuated photon number, heating and optical pulse shape require characterization. An exact M337L4 part was not verified; do not recommend that unconfirmed identifier.

#### **[S047] High Accuracy Calibration of Photon-Counting Detectors On Demand**

OriginalURL: [https://physics.nist.gov/Divisions/Div844/publications/migdall/SPIE65830A\\_Calibration\\_On\\_Demand.pdf](https://physics.nist.gov/Divisions/Div844/publications/migdall/SPIE65830A_Calibration_On_Demand.pdf)

DOI: [10.1117/12.723218](https://doi.org/10.1117/12.723218)

Locator: sections 3-4, pp.3-6.

Access: Primary NIST author conference paper, SPIE 6583, 2007

Applicability limits: Those uncertainty figures are for the demonstrated setups, not a guaranteed 337 nm wide-field two-channel service. A CW efficiency measurement must be checked against actual transient rate, background and detector recovery behavior.

#### **[S048] NPL detector characterisation service**

OriginalURL: <https://www.npl.co.uk/products-services/optical/detector-characterisation>

Locator: Calibrating the spectral responsivity of detectors.

Access: Official current full service page inspected.

Applicability limits: The better-than-0.01% cryogenic-radiometer statement applies at specific visible laser wavelengths; it is not a quoted 337 nm receiver uncertainty. A separate routine single-photon-detector service starts at 380 nm. Analog responsivity coverage does not automatically establish 337 nm photon-counting calibration, timing capability, available booking, or an end-to-end uncertainty. No facility affiliation is claimed.

#### **[S049] OMI collection 4: establishing a 17-year-long series of detrended level-1 b data**

OriginalURL: <https://amt.copernicus.org/articles/15/3527/2022/>

DOI: [10.5194/amt-15-3527-2022](https://doi.org/10.5194/amt-15-3527-2022)

Locator: sections 4.4-4.6; section 5 and Figures 9-11.

Access: Primary open publisher HTML, 14 June 2022; methods and figures inspected.

Applicability limits: Its large CCD instrument and orbit are not this receiver. Do not import its degradation rate or long-exposure correction performance into microsecond data. The row anomaly is probably external obscuration by loose insulation, not ordinary detector radiation aging. Internal LED constancy alone cannot exclude a blocked entrance path.

#### **[S050] An approach to track instrument calibration and produce consistent products with V 8 TOZ**

OriginalURL: <https://amt.copernicus.org/articles/16/2919/2023/>

DOI: [10.5194/amt-16-2919-2023](https://doi.org/10.5194/amt-16-2919-2023)

Locator: Figure 1 and associated introductory calibration paragraphs.

Access: Primary open publisher HTML, 14 June 2023.

Applicability limits: This demonstrates an architecture for separating reference aging from instrument aging, not a universal UV stability guarantee for a Cube Sat. The result is relative temporal stability; initial absolute calibration and retrieval soft-calibration have distinct uncertainties. A single unmonitored LED cannot uniquely separate its own drift from detector gain drift.

#### **[S051] Calibration of radioluminescence detectors for radioactivity measurements**

OriginalURL: <https://oar.ptb.de/files/download/EMPIR.19ENV02.PA.20231027.pdf>

DOI: [10.1016/j.nima.2024.169325](https://doi.org/10.1016/j.nima.2024.169325)

Locator: section 3, pp.4-5; reference detector/calibration arrangement.

Access: Primary author manuscript 26 Oct 2023; journal NIMA 1064, 2024

Conditions/scope: DUV340-HL18 W LED, 340 nm, FWHM 8 nm; monitored dual integrating sphere UV radiance source

Applicability limits: Monitor stability is not total absolute calibration uncertainty or multi-year orbital stability. Broad LED spectrum needs spectral-mismatch correction for the N2 band and actual filter.

#### **[S052] Model independent approach to the single photoelectron calibration of photomultiplier tubes**

OriginalURL: <https://arxiv.org/pdf/1602.03150>

DOI: [10.1016/j.nima.2017.02.086](https://doi.org/10.1016/j.nima.2017.02.086)

Locator: sections 3, 5-7; Eqs.(7), (9), (12); Table 1; Figure 9.

Access: Full primary author manuscript v 2, 18 June 2017; NIM A 863, 35-46.

Applicability limits: The equations assume linear independent response and Poisson photoelectrons; background and under-amplified pulses bias occupancy if misclassified. This calibrates charge per collected photoelectron and multiplication noise, not absolute incident-photon PDE. Keep optics/photocathode calibration separate; do not blindly apply to correlated SiPM avalanches or saturated data.

#### **[S053] Raw photodiode and antenna triggers for Leal et al.(2026) multiband return-stroke study**

OriginalURL: <https://zenodo.org/records/19209986>

DOI: [10.5281/zenodo.19209986](https://doi.org/10.5281/zenodo.19209986)

Locator: Description; Files; v 1 released 2026-03-24.

Access: Official landing metadata/file inventory verified; API 403. NoPSDATA downloaded.

Applicability limits: Compatible Pico Scope software/export and complete relative calibration are required for waveform reanalysis. ENTLN data require an external request; no contact made. No unrestricted data license established from retrieved landing text.

#### **[S054] Six-Channel Spectrophotometers(PH)Onboard JEM-GLIMS**

OriginalURL: [https://www.jstage.jst.go.jp/article/ieejfms/131/12/131\\_12\\_1000/\\_pdf](https://www.jstage.jst.go.jp/article/ieejfms/131/12/131_12_1000/_pdf)

DOI: [10.1541/ieejfms.131.1000](https://doi.org/10.1541/ieejfms.131.1000)

Locator: Table 1, p 1001; sections 2.1-2.2, pp 1001-1002; Figures 3-4.

Access: open primary six-page PDF

Conditions/scope: R 7400-06 UV PMT; R 7400-20 red PMT; S1227-1010BQ broadband PIN Design/preflight paper; 337±5 nm; 42.7 deg UV full FOV; 20 kHz 12-bit; 8 mm PMT photocathode.

Applicability limits: The design sensitivity of 0.1 uW/m2 differs from the later flight table. Telecentric chief-ray control does not establish zero angular spread.

#### **[S055] GSENSE400BSI scientific CMOS image sensor**

OriginalURL: [https://www.gpixel.com/en/pro\\_details\\_1196.html](https://www.gpixel.com/en/pro_details_1196.html)

Locator: specifications and operation modes.

Access: Official current manufacturer product specification.

Applicability limits: A short minimum exposure is not a 50 kHz full-area frame rate. Reducing the ROI changes accepted area/field unless the optics are redesigned. Summed independent read noise scales approximately with square root of pixel count; 1.6 electrons per pixel is not 1.6 electrons for the full receiver. Exact 337 nm QE and flight qualification remain unverified.

#### [S056] H 16722 series cooled PMT module

OriginalURL: [https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99\\_SALES\\_LIBRARY/etd/H16722\\_TPMO1122E.pdf](https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/etd/H16722_TPMO1122E.pdf)

Locator: PDF p.1 specifications and footnotes; p.2 cooling and dimensions.

Access: Official datasheet TPMO 1 122E01, October 2022; current H16722-50 product page also verified.

Applicability limits: Red PMTs need not all have only a few percent QE. But a 5 mm cathode imposes an étendue constraint, and thermal rejection in vacuum needs design. No flight qualification or radiation result is given. Dark anode current is not an RMS noise specification.

#### [S057] S13360 series MPPC electrical and optical characteristics

OriginalURL: [https://hep.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99\\_SALES\\_LIBRARY/ssd/s13360\\_series\\_kapd1052e.pdf](https://hep.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s13360_series_kapd1052e.pdf)

Locator: p.3 electrical/optical table, footnotes 4-5.

Access: Official manufacturer datasheet; p.3 indexed table and footnotes verified.

Applicability limits: Scaling to a larger mosaic scales dark counts and capacitance too. Bias, package/window, temperature and readout must be retained. A spectrum or separately calibrated PDE is needed at 337.1 and 777 nm; nominal peak PDE cannot be reused.

#### [S058] S 8664 series Si APD

OriginalURL: [https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99\\_SALES\\_LIBRARY/ssd/s8664\\_series\\_kapd1012e.pdf](https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s8664_series_kapd1012e.pdf)

Locator: p.1 table, conditions Ta=25 °C.

Access: Official manufacturer datasheet.

Applicability limits: The 420 nm figures are not calibrated 337 or 777 nm values. Large area trades increased capacitance against collection area; the receiver amplifier must be evaluated with that capacitance. Catalog availability does not imply flight qualification.

#### [S059] The SiSMUV Project: Development and Characterization of SiPM-Based UV-Light Detectors for Space Telescope Applications

OriginalURL: <https://inspirehep.net/files/475a891bf3046a48d47231575224af93>

DOI: [10.3390/particles8040092](https://doi.org/10.3390/particles8040092)

Locator: sections 3-4 and 6; printed pp.3-5, 8.

Access: Primary open journal PDF; 27 November 2025

Conditions/scope: S13361-3050-NE-08 8 x 8 array, 3 x 3 mm per tile, 50 micrometre cells; RADIOROC/Artix7 prototype 405 nm laser, 25 plus/minus 1 C, 55.2 V representative bias

Applicability limits: 405 nm response is not measured 337 nm response. Quoted reproducibility is not a full absolute uncertainty budget.

#### [S060] Resolving the signal: precision ADC signal-chain noise questions

OriginalURL: <https://www.ti.com/document-viewer/lit/html/SSZT554/GUID-5FCFDA62-4CDD-403A-969C-EB377113CA8A>

Locator: questions 4-5, 9-10: ENBW, total chain filtering, output-data-rate and clocks.

Access: Official Texas Instruments technical article SSZT 554, Bryan Lizon, January 2019; full text read.

Applicability limits: The article's 6 nV RMS example uses 2.5 samples/s, not 10-50 kS/s; no such low noise is assumed for this photometer. Nonwhite detector/TIA noise and aliased out-of-band noise require PSD integration through the actual chain. A single bandwidth or nominal bit depth does not determine mission photon threshold.

#### [S061] Transimpedance Amplifier Noise Considerations

OriginalURL: <https://www.analog.com/en/resources/technical-articles/transimpedance-amplifier-noise-considerations.html>

Locator: Noise in TIAs; Achieving Higher Bandwidth with Higher Gain TIAs; Figures 6-9.

Access: official measured circuit/appnote

Conditions/scope: LTC6268 FET-input amplifier; 499 kohm feedback

Applicability limits: Specific low-capacitance setup; not prooflargearea UV receiver reaches equalnoise. Counterexample disproves a universal  $1 \text{ e } 10 \text{ V/A} \cdot \text{Hz}$  limit, not fundamental photonbudget limitations.

#### [S062] Technical note: Si APD

OriginalURL:

[https://hep.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99\\_SALES\\_LIBRARY/ssd/si-apd\\_kapd9007e.pdf](https://hep.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/si-apd_kapd9007e.pdf)

Locator: section 2-1 p.2; section 2-3 equations 2-2 and 2-3 p.3; section 2-5 p.5.

Access: Official manufacturer technical note, full 10-page PDF.

Applicability limits: Multiplying an already multiplied total dark current by  $M^2$  would overestimate the noise incorrectly. A catalog total dark current alone cannot uniquely partition bulk and surface noise. For fixed measured total dark current, the inferred dark PSD lies between  $2 \text{ qI}_D$  and  $2 \text{ qMFI}_D$  under this model, not a single universal value.

#### [S063] CALIPSO lidar Level 1 B data description and quality summary, version 5

OriginalURL: [https://ntrs.nasa.gov/api/citations/20260000651/downloads/cal\\_lid\\_l1\\_V5-00\\_desc\\_qs.pdf](https://ntrs.nasa.gov/api/citations/20260000651/downloads/cal_lid_l1_V5-00_desc_qs.pdf)

DOI: [10.5067/CALIPSO/CALIPSO/CAL\\_LID\\_L1\\_Data\\_Description\\_Document\\_V5](https://doi.org/10.5067/CALIPSO/CALIPSO/CAL_LID_L1_Data_Description_Document_V5)

Locator: Appendix 3, printed pp.62-64; Figures A 3-1 to A 3-3.

Access: Official NASA report, 21 January 2026; Appendix 3 updated 5 October 2025.

Applicability limits: A lidar range tail converts to time using  $2 \text{ d/c}$ . These observations do not establish a  $0.2 \text{ ms}$  tail for our detector. The useful requirement is amplitude- and duration-dependent impulse/step characterization: cloud timing and receiver timing cannot be separated by assuming a single universal linear kernel.

#### [S064] Design of photomultiplier output circuits for optimum amplitude or time response

OriginalURL: [https://et-enterprises.com/images/technical\\_papers/rp065\\_design\\_of\\_PMT\\_output\\_circuits.pdf](https://et-enterprises.com/images/technical_papers/rp065_design_of_PMT_output_circuits.pdf)

Locator: section 3, printed page 2; Figure 4; section 5.3.

Access: Official ET Enterprises technical reprint R/P 065 by A.G. Wright

Applicability limits: Legacy example amplifiers and nanosecond scintillation pulses are not our chosen receiver. Actual transfer function, saturation and recovery must be measured over the millisecond pulse and background range.

#### [S065] DLPCA-200 Variable Gain Low Noise Current Amplifier

OriginalURL: <https://www.femto.de/images/pdf-dokumente/de-dlpca-200.pdf>

Locator: p.1 block diagram; p.2 specifications and measurement footnote.

Access: Official manufacturer 5-page PDF, revision R 19, 2 January 2019; current product listing verified.

Applicability limits: Noise at one frequency must not be multiplied by square root of  $50 \text{ kHz}$  and substituted for the measured integrated figure. Detector capacitance adds voltage-noise current. Bench hardware is not flight qualified; this is a counterexample to the claimed universal gain-bandwidth bound.

#### [S066] The Modular Multispectral Imaging Array (MMIA) of the ASIM payload

OriginalURL: [https://backend.orbit.dtu.dk/ws/files/175725338/The\\_Modular\\_Multi.pdf](https://backend.orbit.dtu.dk/ws/files/175725338/The_Modular_Multi.pdf)

DOI: [10.1007/s11214-019-0593-y](https://doi.org/10.1007/s11214-019-0593-y)

Locator: section 3.3, printed pp.9-11 and Table 5; section 4.1 p.12.

Access: Primary published author-hosted full manuscript.

Applicability limits: The  $250 \text{ nm}$  internal check does not establish absolute drift of the whole  $337$  or  $777 \text{ nm}$  optical path. Heritage proves an architecture, not the performance of a  $25 \text{ mm}$  entrance aperture within the same volume and power. Exact PMT part numbers are not published here.

#### [S067] What the Nyquist criterion means to your sampled data system design

OriginalURL: <https://www.analog.com/media/en/training-seminars/tutorials/MT-002.pdf>

Locator: pp.1, 4-8, Figures 1, 4-7; baseband sampling and antialias filtering.

Access: Official Analog Devices tutorial by Walt Kester; full 12-page PDF, Rev.A 10/08.

Applicability limits: A Nyquist frequency does not specify a practical filter cutoff or its stopband margin. The tutorial's separate bandpass-undersampling examples do not apply directly to a DC-to-transient photometer. Exact sub-sample parameter inference requires pulse-model, phase, noise and filter assumptions; raw cadence alone does not validate rise-time discrimination.

#### [S068] A Multiband Optical-Radio View of Lightning Return Strokes Exposes Divergent $337/777 \text{ nm}$ Emission Dynamics

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2026GL123245>

DOI: [10.1029/2026GL123245](https://doi.org/10.1029/2026GL123245)

Locator: sections 2.1-2.2, 3.2; Table 1; Figures 3-5.

Access: Full primary publisher HTML now verified using?af=R after initial timeout. Table 1 and relative calibration methods inspected.

Conditions/scope: Thorlabs APD410A2/M 337 nm; APD410A/M 777 nm; Pico Scope 4824 A Ground lightning near Langmuir Lab; approximately 20 deg FOV; 5 MHz 12-bit digitizer; 2 s records, .6 s pretrigger.

Applicability limits: Does not demonstrate faint orbital threshold, absolute photon-number calibration or flight qualification. Cannot reuse ground extinction above 15 km.

#### **[S069] Transimpedance amplifiers: Reaching high gain, low noise and high bandwidth**

OriginalURL: <https://doi.org/10.1016/j.measen.2026.102011>

DOI: [10.1016/j.measen.2026.102011](https://doi.org/10.1016/j.measen.2026.102011)

Locator: sections 2.2, 2.4.1, 3.1.3-3.1.4; Tables 1, 3, 4.

Access: Primary publisher search-index full text plus author institution metadata; direct publisher open returned 403. Published online 24 June 2026, volume 46 August 2026.

Applicability limits: This refutes a universal 1 nA amplifier floor, but gives no 337 nm detector-coupled or radiation-qualified result. Actual sensor/cable capacitance matters. The reported average density is RMS divided by square root of nominal bandwidth, not a measured flat white-noise PSD. Its 250 kHz variant has substantially higher 66.18 pA RMS noise.

#### **[S070] Guidelines for accurate evaluation of photodetectors based on emerging semiconductor technologies**

OriginalURL: <https://www.repository.cam.ac.uk/items/d1562912-fd22-492e-bbd1-d4f1474ef69f>

DOI: [10.1038/s41566-025-01759-1](https://doi.org/10.1038/s41566-025-01759-1)

Locator: Noise, NEP/detectivity, temporal response and benchmarking sections.

Access: Peer-reviewed consensus article; accepted manuscript available at Cambridge, repository DOI 10.17863/CAM.122981

Applicability limits: Method guidance is not experimental performance of a candidate flight detector. Responsivity and timing measured at bright illumination cannot automatically establish behavior near the faint-event threshold.

#### **[S071] Ultra-narrowband optical bandpass filters with large format and improved temperature stability**

OriginalURL: [https://alluxa.com/wp-content/uploads/2014/09/Ultra-narrowband-optical-bandpass-filters-with-large-format-and-improved-temperature-stability\\_2.pdf](https://alluxa.com/wp-content/uploads/2014/09/Ultra-narrowband-optical-bandpass-filters-with-large-format-and-improved-temperature-stability_2.pdf)

Locator: p.2 f/5 modeled cone; p.3 thermal results.

Access: Primary manufacturer-authored 2014 technical paper, 3 pages.

Applicability limits: Neither thermal coefficient is a measured 337 nm property. The result does not solve a 60-90° full field in a compact receiver. Environmental cycling and hard coatings do not by themselves establish radiation, contamination, or vacuum qualification.

#### **[S072] 337-1.5 OD 6 Ultra Narrow Bandpass Filter, SKU 7021**

OriginalURL: <https://alluxa.com/optical-filter-catalog/ultra-narrow-bandpass/337-1-1-5-od6-ultra-narrow-bandpass/>

Locator: product specifications table.

Access: Official current catalog, 12.5 mm product; page specifications verified.

Applicability limits: The OD 6 product name does not guarantee visible/NIR blocking. Leakage must be integrated over the detector response, especially for silicon. The 25 mm page did not expose a complete primary specification during this review; secondary reseller values were not transferred. No space qualification follows from the catalog.

#### **[S073] Focal plane optics in far-infrared and submillimeter astronomy**

OriginalURL: <https://ntrs.nasa.gov/api/citations/19860004735/downloads/19860004735.pdf>

Locator: printedpp 5-7; equation 1; section 3.

Access: open NASA technicalreport

Applicability limits: The geometrical-optics relation is transferable; the far-infrared materials, bolometer performance and diffraction numbers are not. Finite filter cones and detector acceptance constrain practical ultraviolet throughput.

#### **[S074] Laboratory Calibration of the Optical Transient Detector and the Lightning Imaging Sensor**

OriginalURL: [https://ghrc.nsstc.nasa.gov/pub/doc/preservation/lis/documents/lis-otd/calibration\\_data/LabCalofOTDandLIS.pdf](https://ghrc.nsstc.nasa.gov/pub/doc/preservation/lis/documents/lis-otd/calibration_data/LabCalofOTDandLIS.pdf)

DOI: [10.1175/1520-0426\(2000\)017<0905:LCOTOT>2.0.CO;2](https://doi.org/10.1175/1520-0426(2000)017<0905:LCOTOT>2.0.CO;2)

Locator: printed pp.908-910, sections 4-5; p.912 discussion.

Access: Primary journal article preserved by NASA GHRC

Applicability limits: These are 777 nm imager results, not a ready 4 nm 337 nm Cube Sat design. Passband measurements excluded OOB regions, whose verification was separate vendor testing.

#### **[S075] NIST oxygen persistent lines and wavelength convention**

OriginalURL: [https://physics.nist.gov/PhysRefData/Handbook/Tables/oxygentable3\\_a.htm](https://physics.nist.gov/PhysRefData/Handbook/Tables/oxygentable3_a.htm)

Locator: O I 7771.94, 7774.17, 7775.39 Å rows; Handbook section A Wavelengths.

Access: Official NIST tables and handbook wavelength convention; full table inspected.

Applicability limits: Source spectra, solar standards, monochromator calibration and filter specification must use a declared common convention. An air-vacuum coordinate conversion is separate from an actual coating passband change when changing ambient pressure. Both require metadata.

#### **[S076] Atomic oxygen photometric temperature of lightning and its sub-processes with SOPAPILLA**

OriginalURL: <https://www.nature.com/articles/s41598-025-34189-8>

DOI: [10.1038/s41598-025-34189-8](https://doi.org/10.1038/s41598-025-34189-8)

Locator: Methods: Instruments, Data analysis; Figure 6.

Access: open publisher fulltext

Conditions/scope: PDA100A2 photodiodes; 20 dB gain Ground NIR channels 777/844/926 nm 1 nm filters; 812 nm 10 nm continuum; 20 deg FOV; 800 kHz sampling.

Applicability limits: NIR bright-light conditions do not validate faint 337 nm receiver. Authors average blocking 1 e<sup>-4</sup> from Xray to far IR lacks a source-specific measured blocking curve; do not use as verified optical-density requirement.

#### **[S077] Ice Cube sensitivity for low-energy neutrinos from nearby supernovae**

OriginalURL: <https://arxiv.org/pdf/1108.0171>

DOI: [10.1051/0004-6361/201117810](https://doi.org/10.1051/0004-6361/201117810)

Locator: section 3.2, PDF pp.5-6; Figures 2-3.

Access: Primary author manuscript v 2, September 2011; section 3.2 and figures inspected. PDF rendering shows a later automatic 2018 header.

Applicability limits: This is a cold underwater/ice assembly, not a satellite rate prediction or proof that our fused-silica filter will behave identically. It demonstrates that millisecond internal light bursts are physically possible; a >3 ms duration criterion alone is not a universal particle/noise veto. Copying the dead-time cure would impair this mission's rise-time measurement.

#### **[S078] Application of neural networks to classification of data of the TUS orbital telescope**

OriginalURL: <https://arxiv.org/pdf/2106.03361>

Locator: section 2 pp.3-4; section 3.1 pp.5-8.

Access: Primary author manuscript v 2, 1 July 2021, full PDF.

Applicability limits: Trigger fractions are selected acquisition statistics, not a transferable probability for this photometer. A UV-chain-only artifact need not appear in a red null channel. The separate first-day high-voltage/daylight fault damaged 51 channels; it must not be presented as cumulative radiation degradation.

#### **[S079] Mitigating radiation damage of single photon detectors for space applications**

OriginalURL: <https://link.springer.com/article/10.1140/epjqt/s40507-017-0062-z>

DOI: [10.1140/epjqt/s40507-017-0062-z](https://doi.org/10.1140/epjqt/s40507-017-0062-z)

Locator: sections 2.1-2.2, 3, 4.1-4.2; Figures 3, 5-7; Table 2.

Access: Primary published open-access full text verified.

Applicability limits: Specific bench samples and 780 nm characterization do not predict 337 nm sensitivity or this 550 km mission. PMT sample statistics were small and unaged, with a suspect outlier; no detector-class radiation ranking follows.

#### **[S080] Repeated radiation damage and thermal annealing of avalanche photodiodes**

OriginalURL: <https://link.springer.com/article/10.1140/epjqt/s40507-021-00103-0>

DOI: [10.1140/epjqt/s40507-021-00103-0](https://doi.org/10.1140/epjqt/s40507-021-00103-0)

Locator: sections 2-4; Figures 3-7; Appendix annealing time.

Access: Primary open-access full text verified; raw datasets available only on author request, which was not made.

Applicability limits: The stated orbital years assume 600 km and 10 mm Al; this is accelerated bench evidence, not flight validation. Conditional versus periodic differences may include small-sample variation. A 2 kcps maintenance threshold chosen for QKD is not a photometer threshold.

**[S081] Characterization of more than three years of in-orbit radiation damage of SiPM s on GRBA lpha and VZLUSAT-2 Cube Sats**

OriginalURL: <https://arxiv.org/html/2411.00607v2>

DOI: [10.1016/j.nima.2025.170513](https://doi.org/10.1016/j.nima.2025.170513)

Locator: sections 3.1, 3.2, 4.1, 4.2; Figures 9, 11-16; equations 2, 5.

Access: open author manuscript; complete methods inspected

Conditions/scope: Hamamatsu S13360-3050 PE; 4 parallel/channel, 8 total Initial 550 km and 535 km sun-synchronous orbits; 2-2.5 mm PbSb shield; evolving orbit and temperature; 10 us shaping, 15 us processing.

Applicability limits: Reported DCR is not intrinsic primary avalanche DCR. AP8 flux uncertainty factor two; detailed shielding matters.

**[S082] In-orbit radiation damage characterization of SiPM s in the GRID-02 Cube Sat detector**

OriginalURL: <https://arxiv.org/html/2205.10506v2>

DOI: [10.1016/j.nima.2022.167510](https://doi.org/10.1016/j.nima.2022.167510)

Locator: sections 3, 4; equations 2, 6; device/current figures.

Access: open author manuscript; methods and measured slopes inspected

Conditions/scope: Micro FJ-60035-TSV; 16 parallel/channel, four channels 457×467 km, 97.2 deg; 28.5 V fixed bias; current normalized 5 C; no active cooling.

Applicability limits: Flight altitude is lower than 550 km. Scintillator ke V noise cannot directly become 337 nm optical NEP.

**[S083] Comparing a radiation damage model for avalanche photodiodes through in-situ observation of Cube Sat based devices**

OriginalURL: <https://www.nature.com/articles/s42005-025-02042-z>

DOI: [10.1038/s42005-025-02042-z](https://doi.org/10.1038/s42005-025-02042-z)

Locator: Methods: Radiation effects on GM-APDs; Results Figs.6-7; Data availability.

Access: Open primary journal article

Conditions/scope: Two SAP500 GM-APDs; free-running passive quench with feedback maintaining excess bias Spoo Qy-1, 51.6 degree inclination, altitude 418 to 378 km during 600 days; DCR comparison normalized to 10 C

Applicability limits: Part-to-part variation and anisotropic geometry prevent transferring a universal growth coefficient to a fixed 550 km polar orbit. Underlying data and code are available on request, not public.

**[S084] Total Ionizing Dose Effects on CMOS Image Sensor for the ULTRASAT Space Mission**

OriginalURL: <https://arxiv.org/html/2306.15307v1>

Locator: sections 2-5; Figures 2-4.

Access: open author manuscript, NIMA 1054(2023)168463

Conditions/scope: Tower 180 nm 4 Tteststructures similar tofinal CIS Co 60 HZB/CERN; maximumapplicablebias; roomtemperature; measurements up 2 monthsafterirradiation.

Applicability limits: These are test structures, not a final flight device; nominal 300 s exposures differ greatly from a 20 us transient sample. Dark-current random telegraph signals and prompt charge hits require separate treatment. Reported dwell times range from microseconds to weeks.

**[S085] SG01D-18S silicon carbide UV photodiode datasheet**

OriginalURL: <https://sglux.de/download/photodiodes/SG01D-18S.pdf>

Locator: specification table; spectral-response curve.

Access: Official manufacturer datasheet; revision 7.0

Conditions/scope: sglux SG01D-18S, 0.50 square millimetre SiC photodiode Dark current at 25 C, 1 V reverse bias; peak responsivity at 280 nm

Applicability limits: Peak responsivity must not be applied at 337 nm. No internal multiplication; capacitance and front-end voltage noise remain relevant.

**[S086] 9111B series data sheet, Issue 9, 25 January 2016**

OriginalURL: [https://et-enterprises.com/images/data\\_sheets/9111B.pdf](https://et-enterprises.com/images/data_sheets/9111B.pdf)

Locator: p 1 window/spectral/active-area tables; p 2 ordering and flying-lead drawing.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S087] 9113B series data sheet, Issue 7, 7 May 2015**

OriginalURL: [https://et-enterprises.com/images/data\\_sheets/9113B.pdf](https://et-enterprises.com/images/data_sheets/9113B.pdf)

Locator: p 1 characteristics/window table; p 2 ordering information and 9113FLB drawing.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S088] HV2520CN series data sheet**

OriginalURL: [https://et-enterprises.com/images/data\\_sheets/HV2520CN.pdf](https://et-enterprises.com/images/data_sheets/HV2520CN.pdf)

Locator: p 1 description and schematic; p 2 mating/ordering information.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S089] ET Enterprises: Precautions**

OriginalURL: <https://et-enterprises.com/support/precautions>

Locator: Photomultiplier Envelope; General Operation; Sockets and Overcaps.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S090] Excelitas Canada operations, Vaudreuil-Dorion**

OriginalURL: <https://prod.excelitas.com/location/montreal-qc-canada-operations>

Locator: Facility description: silicon and III-V sensors/emitters.

Access: web tool full text, 2026-10-22

**[S091] First Sensor APD arrays official selector**

OriginalURL: <https://www.first-sensor.com/en/produkte/optische-sensoren/detektoren/avalanche-photodioden-arrays-apd-arrays/>

Locator: Multi-Element Arrays table, order 3005259 and 3001411; evaluation board table.

Access: web tool full text, 2026-10-22

**[S092] ESA ESCC Process Capability Approval List entry for First Sensor Lewicki**

OriginalURL: <https://escies.org/download/webDocumentFile?id=70759>

Locator: ESCC/RP/HP/PCAL 008 Issue 15, printed pp 24-25, §5.3.2.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S093] LASER COMPONENTS Detector Group manufacturing location**

OriginalURL: <https://www.lasercomponents.com/en/company/about-us/laser-components-group/laser-components-detector-group/>

Locator: Chandler, Arizona detector manufacturing description.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S094] SUR-Series UV-enhanced Silicon Avalanche Photodiode, V 09, 01/20**

OriginalURL: [https://www.lasercomponents.com/fileadmin/user\\_upload/home/Datasheets/lc-apd/sur-series.pdf](https://www.lasercomponents.com/fileadmin/user_upload/home/Datasheets/lc-apd/sur-series.pdf)

Locator: p 1 package/active size; p 3 electrical characteristics; p 5 ordering; p 7 cooled versions.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

Conditions/scope: Marked PRELIMINARY throughout; this is the file linked by the current selector, not proof of current guaranteed production acceptance limits

**[S095] Photek Photomultiplier Tube DS 006 Rev 05 Oct 21**

OriginalURL: <https://www.photek.com/wp-content/uploads/2021/10/PH-DS006-PhotomultiplierTube-Rev05-Oct21.pdf>

Locator: pp 1-2 detector options/QE curves; p 5 environmental testing and ordering table; p 6 UK address.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

**[S096] Tandon et al., In-orbit Performance of UVIT and First Results, public author manuscript**

OriginalURL: <https://arxiv.org/pdf/1612.00612>

DOI: [10.1007/s12036-017-9445-x](https://doi.org/10.1007/s12036-017-9445-x)

Locator: printed pp 3, 5-6 §2.2; p 11 §3.3; pp 13-14 first VIS images.

Access: Public supplier/reference document, scope qualified by the linked audit; no unrecorded full-text access claimed.

Conditions/scope: Public arXiv 1612.00612 manuscript, posted 2 December 2016; not asserted identical to the 2017 version of record

**[S097] Luque et al.2020: Modeling lightning observations from space-based platforms(CloudScat.jl 1.0)**

OriginalURL: <https://gmd.copernicus.org/articles/13/5549/2020/>

DOI: [10.5194/gmd-13-5549-2020](https://doi.org/10.5194/gmd-13-5549-2020)

Locator: Sections 2-4: Monte Carlo cloud source/observer implementation and applications.

Access: Open primary article; source/model methods inspected in project and official article reopened 22 October 2026

Rights/access: Article CC BY 4.0. No third-party restricted raw observations reproduced.

**[S098] Latitude dependence of narrow bipolar pulse emissions; author dissertation count audit**

OriginalURL: <https://www.sciencedirect.com/science/article/abs/pii/S136468261500053X>

DOI: [10.1016/j.jastp.2015.03.005](https://doi.org/10.1016/j.jastp.2015.03.005)

Locator: Ahmad 2014 thesis section 3.3 printedp 43; Ahmad 2015 abstract; Thesispp 43, 46-48; 2015 abstract.

Access: 2015 publisher abstract and snippets; full 2014 Uppsala author dissertation downloaded

**[S099] AIRFLY measured pressure, temperature and absolute 337 nm high-energy fluorescence yield**

OriginalURL: <https://arxiv.org/abs/1210.6734>

DOI: [10.1016/j.astropartphys.2012.12.006](https://doi.org/10.1016/j.astropartphys.2012.12.006)

Locator: AIRFLY 2013 absolute result; AIRFLY 2007 pressurepaper; AIRFLY 2008 Table 1 and Eq 1-3.

Access: Three openauthor PDFs downloaded, text extracted, SHA 256 saved in emission\_kinetics/retrieval.json

Applicability limits: The 216.65 K case is an extrapolation, not a measured flight cloud profile or source electron-energy distribution. A nanosecond excited-state lifetime cannot constrain a continually re-excited source to a nanosecond optical duration.

**[S100] Height Determination of a Blue Discharge Observed by ASIM/MMIA on the International Space Station**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022JD037460>

DOI: [10.1029/2022JD037460](https://doi.org/10.1029/2022JD037460)

Locator: Publicfig 5.fig; MATLAB axis YL label properties; fig 5 line 03/02; Section 3 and Figure 3; Section 6 and Supplement Figure S1; Author Figure 5 arrays; analyze\_bath\_waveform.py.

Access: Public 95.1 MB ZIP inspected by HTTPR ange; selected MATLAB figures retrieved with ZIPCRC checks. Full paper inspected. Numeric figure arrays decoded without executing MATLAB.

**[S101] Ordinary/mixed optical-radio context in public BATH-01103 Figure 4**

OriginalURL: <https://researchdata.bath.ac.uk/1103/>

DOI: [10.1029/2022JD037460](https://doi.org/10.1029/2022JD037460)

Locator: Published Figure 4 numeric axes andlineobjects.

Access: Selected MATLAB figure entry retrieved by HTTPR ange, ZIPCRC/SHA 256 verified; boundedparser readsnumericdata without executing MATLAB objects

Applicability limits: A useful replay fixture, with no classifier confusion matrix or population completeness.

**[S102] Group Data and Detection Efficiency Analysis for the Modular Multispectral Imaging Array**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2025JD045209>

DOI: [10.1029/2025JD045209](https://doi.org/10.1029/2025JD045209)

Locator: Abstract; pbitzer/mmia\_groupingv 0.1.1 grouping.pyfind\_clusters.

Access: Publisher/full redirects toabstract; abstract anddata statement verified, full methods not obtained. Public source tagv 0.1.1 inspected statically, not executed.

**[S103] Global Distribution and Spectral Features of Intense Lightning by the ISUAL Experiment**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022JD036473>

DOI: [10.1029/2022JD036473](https://doi.org/10.1029/2022JD036473)

Locator: Independentparsers ofpublishedcatalogue; matchesall 6 publishedmarginalsexactly; audit\_chuang 2022\_catalog.py.

Access: Full primary HTML; 18, 338, 400 byte CCBY catalogue retrieved with exact supplied MD 5 verification

Applicability limits: Selected intense limb lightning; changing high voltage and response; fixed 22:30-23:20 local time; assumed 10 km geolocation height. The SP5 band near 774-785 nm differs from the proposed 4 nm filter; no matched photon-threshold comparison is

established.

**[S104] Measurement of the electric field distribution in streamer discharges**

OriginalURL: <https://pure.tue.nl/ws/portalfiles/portal/350964030/PhysRevResearch.7.013051.pdf>

DOI: [10.1103/PhysRevResearch.7.013051](https://doi.org/10.1103/PhysRevResearch.7.013051)

Locator: Laboratory streamer electric-field method and 70 mbar profiles; optical curves normalized, not an absolute 337 nm-current calibration..

Access: Complete primary main paper; supplemental access failed

**[S105] JUICE-MAJIS Earth-flyby lightning spectra**

OriginalURL: <https://angeo.copernicus.org/articles/44/435/2026/>

DOI: [10.5194/angeo-44-435-2026](https://doi.org/10.5194/angeo-44-435-2026)

Locator: Instrument/resultssections; Spectralresultfigure/text.

Access: Fullopenprimary HTML

Applicability limits: The stated raw MAJIS data access remains proprietary until about six months after the 2029 EGA3 encounter; no archive spectra were downloaded. No 337/777 ratio, intrinsic line width, source-current calibration or mission population inference follows.

**[S106] Blue Flashes as Counterparts to Narrow Bipolar Events: The Optical Signal of Shallow In-Cloud Discharges**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021JD035013>

DOI: [10.1029/2021JD035013](https://doi.org/10.1029/2021JD035013)

Locator: Table 1.

Access: Full publisher HTML inspected; numerical Table 1 retained as published

Applicability limits: Overlaps Liu Nature 2021 twelveeventstudy and 2025 elves subset; do not add counts as independent samples. Shows source population not universally >3 ms. No completeness.

**[S107] Multi-Pulse Corona Discharges in Thunderclouds Observed in Optical and Radio Bands**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GL098938>

DOI: [10.1029/2022GL098938](https://doi.org/10.1029/2022GL098938)

Locator: Section 3.

Access: Full text accessible via publisher web reader; PMC frontpage presented browser challenge

**[S108] Night, cloud shadow and spacecraft eclipse are different conditions**

OriginalURL: [https://gssc.esa.int/navipedia/index.php/Satellite\\_Eclipses](https://gssc.esa.int/navipedia/index.php/Satellite_Eclipses)

Locator: audit\_night\_selection.py.

Access: Primary ESA technical equation plus NASA source and GOLD twilight paper

**[S109] Remote Sensing of Source Currents of Narrow Bipolar Events Using Measured Electric Fields**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023GL107789>

DOI: [10.1029/2023GL107789](https://doi.org/10.1029/2023GL107789)

Locator: Sections 2.2 and 3, equations 7-10; Section 3 Figure 3; Erratum, corrected 29 March 2025.

Access: Full publisher HTML, including March 2025 erratum, inspected. Public code/data DOI 10.26208/xtw 7-zk 59 metadata retrieved; actual archive files not retrieved.

Applicability limits: Forward reproduction demonstrates consistency within the assumed source model, not uniqueness across geometries or current profiles. The paper explicitly says deconvolution non-uniqueness is not addressed. No optical/current calibration or new 337 nm measurements.

**[S110] Global Distribution of Key Features of Streamer Corona Discharges in Thunderclouds**

OriginalURL: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022JD037535>

DOI: [10.1029/2022JD037535](https://doi.org/10.1029/2022JD037535)

Locator: Figure 5 caption; Figure 6 caption; Table 1; Section 4 paragraph after Figure 6; concluding paragraph; Section 3, Table 1; Figure 10 caption.

Access: Full text accessible through web reader; publisher shell GET previously 403; author-repository PDF also located but not downloaded

#### [S111] HYGEO public bulk-ice GHM optical-property table and SMART-G reader

OriginalURL: [https://docs.hygeos.com/public.php/webdav/ic\\_baum\\_ghm\\_sol.nc](https://docs.hygeos.com/public.php/webdav/ic_baum_ghm_sol.nc)

Locator: Native 330/340 nm, 10 micrometre effective-radius scalar P 11 slice; 594 angle nodes; verified extraction from full Net CDF..

Access: Public model file retrieved and private subset verified against full Net CDF; new revision used retained optical-model input.

Conditions/scope: Scalar phase, linear wavelength interpolation and assumed SSA 1. These are modeled bulk ice properties, not a measured anvil.

Applicability limits: No native phase-grid/habit convergence or actual event validation. Warren-Brandt ultraviolet imaginary-index upper-limit assumptions do not establish real ice/impurity absorption.

Rights/access: Raw full LUT and private subset are not redistributed by these PDFs. Original provider link and derived model diagnostics only.

#### [S112] Physically Based Rendering, 4 th edition: Diffuse Reflection

OriginalURL: [https://www.pbr-book.org/4ed/Reflection\\_Models/Diffuse\\_Reflection](https://www.pbr-book.org/4ed/Reflection_Models/Diffuse_Reflection)

Locator: Lambertian reflection model and radiance/irradiance normalization..

Access: Official author-published technical reference used for the ideal reflection law.

Conditions/scope: BRDF= $\rho/\pi$ ; own finite-FOV/delay integration in this study.

Applicability limits: A real cloud BRDF and internal residence time are not measured by this surface law.

Rights/access: Original technical reference linked; own derived integrals only.

#### [S113] Sci Py official Poisson distribution API

OriginalURL: <https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.poisson.html>

Locator: Methods sf/logs; Notes PMF.

Access: Official numerical API documentation checked by the statistical study; software versions retained in its receipt.

Conditions/scope: Numerical implementation documentation; web manual 1.18.0, installed library 1.18.1.

Applicability limits: Implementation documentation is not an independent experiment or instrument validation.

Rights/access: Documentation linked; generated statistical results and own derivations only.

#### [S114] Sci Py official binomial distribution API

OriginalURL: <https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.binom.html>

Locator: Methods sf; Notes binomial PMF.

Access: Official numerical API documentation checked by the statistical study; software versions retained in its receipt.

Conditions/scope: On/off conditional test implementation.

Applicability limits: Implementation documentation is not an independent experiment or instrument validation.

Rights/access: Documentation linked; generated statistical results and own derivations only.

#### [S115] Sci Py official chi-square distribution API

OriginalURL: <https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.chi2.html>

Locator: Methods ppf/isf.

Access: Official numerical API documentation checked by the statistical study; software versions retained in its receipt.

Conditions/scope: Poisson interval inversion.

Applicability limits: Implementation documentation is not an independent experiment or instrument validation.

Rights/access: Documentation linked; generated statistical results and own derivations only.

#### [S116] Num Py official Generator.poisson API

OriginalURL: <https://numpy.org/doc/stable/reference/random/generated/numpy.random.Generator.poisson.html>

Locator: Generator.poisson; Notes PMF.

Access: Official numerical API documentation checked by the statistical study; software versions retained in its receipt.

Conditions/scope: Synthetic exact Poisson variate generator; current web manual differs from installed 2.3.5.

Applicability limits: Implementation documentation is not an independent experiment or instrument validation.

Rights/access: Documentation linked; generated statistical results and own derivations only.