

The Lavender Flash of August 9th

Lightning colorimetry from plasma physics to webcam Bayer

CMU Skyline Monitor — pandr — proofsandreasons.io*

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Abstract

At 00:11 EDT on 9 August 2026, a fixed-exposure skyline camera in Pittsburgh recorded a single frame in which an overcast midnight sky turned pale lavender: sky-band mean $(R, G, B) = (172, 170, 223)$ against a sodium-amber baseline of $(22, 19, 7)$. We treat this as a closure test: can the color be predicted from the physics of lightning emission, propagated through cloud, air, and the camera’s color pipeline? A three-component spectral model—a 30 000 K continuum standing in for free-free and free-bound emission, N II and hydrogen Balmer lines, and the N_2^+ first-negative band system—is integrated against approximate Bayer sensitivities with daylight (5600 K) white-balance gains, the configuration the instrument locks by design. The measured chromaticity is reproduced to one digital number by a mixture of $\sim 20\%$ continuum, 65% atomic-line, and 12–21% molecular-band energy, the molecular range bracketed by the optically-thick (Planck) and optically-thin (Kramers) continuum limits. Atomic lines and continuum alone cannot reach the observed blueness: the violet N_2^+ contribution is *required* under either limit. We detail the emission components and how the degeneracy could be broken, connect the N_2^+ bands to lightning’s role in nitrogen fixation, and close with the color theory of a purple no eye witnessed.



Figure 1: Three consecutive fixed-exposure reference frames (100 ms, gain and white balance locked), night of 8–9 August 2026. Fixed light sources are unchanged across the triplet (lit windows $162 \rightarrow 174 \rightarrow 161$; lamp cores $242 \rightarrow 250 \rightarrow 243$), ruling out an exposure or gain excursion: the middle frame records real, additive, sky-borne light.

1 The observation

The monitor captures a radiometric reference frame of the Carnegie Mellon skyline every five minutes with sun-elevation-keyed manual exposure, fixed gain, and fixed 5600 K white balance. On the night in question the log shows one anomalous sample: full-frame brightness 138.7 (neighbors 19–37) and sky color `#b9b5ed`. The 100 ms exposure integrated one or more strokes of

*Operated by Simon DeDeo (Carnegie Mellon University). Analysis and code developed with AI assistance (Claude, Anthropic); the human operator is responsible for all claims, citations and errors.

a flash whose light, diffused by the overcast deck, illuminated the scene to twilight levels (Fig. 1). Two later samples (00:33, 00:39) show weak blue excursions consistent with more distant flashes. Linearizing the sRGB-encoded means [9] and subtracting the baseline frame gives the flash-only linear color

$$(r, g, b)_{\text{flash}} = (0.405, 0.396, 0.736), \quad R/G = 1.023, \quad B/G = 1.860. \quad (1)$$

Blue far above green, red slightly above green: pale lavender. The question is whether these two ratios are quantitatively consistent with what lightning emits.

2 Physics: the anatomy of the emission

2.1 The channel

A return stroke drives ~ 30 kA through a centimeter-scale channel, shock-heating it to a peak of 28 000–31 000 K within microseconds [17, 20, 21]. For the first microseconds the channel is optically thick and radiates as a quasi-blackbody; it becomes transparent (except in strong line cores) as it expands and cools [28]. Electron densities inferred from the Stark broadening of $\text{H}\alpha$ start near 10^{18} cm^{-3} and fall an order of magnitude within tens of microseconds [27]; the temperature falls through ~ 20 000 K on the same timescale and reaches ~ 10 000 K by $50 \mu\text{s}$ [17]. A camera exposure of 100 ms therefore integrates the *entire* thermodynamic history of every stroke it catches—and a typical cloud-to-ground flash contains 3–5 strokes spread over 200–300 ms [21], so the frame may hold several. This time-integration is the physical origin of the mixture model below, and (§2.6) of its degeneracy.

2.2 The continuum

Beneath the lines lies a genuine continuum, dominated not by blackbody emission but by two free-electron processes in the transparent plasma: free–free bremsstrahlung, electrons scattering in ion fields, and free–bound radiative recombination, electrons captured onto H^+ , N^+ , and O^+ [18, 28, 32]. Recombination continua carry series-edge structure rather than a Planck shape: the hydrogen Balmer continuum jumps at 364.6 nm, just outside the camera passband, while the Paschen continuum (captures to $n = 3$) spans the entire visible band with its edge at 820 nm and an intensity rising toward the blue. The *slope* of this continuum depends on the channel’s opacity state. While optically thick (the first microseconds), it radiates a Planck curve—an effective $\lambda^{-3.5}$ across our band at 30 000 K. Once transparent, free–free and free–bound emission follow the much flatter Kramers form, $\varepsilon_\lambda \propto \lambda^{-2} e^{-hc/\lambda kT}$, an effective $\lambda^{-1.1}$: distinctly redder at the same temperature. The time-integrated continuum is an unknown blend of the two phases, so we fit the mixture model with each limit and let them bracket the answer (§2.5). In time-resolved spectra the continuum flashes brightest in the first few microseconds, when the channel is hottest and densest [17]; its share of the *time-integrated* visible energy is the model’s w_c .

2.3 The atomic lines

At channel temperatures ($kT \simeq 2.6$ eV) collisional excitation populates levels tens of eV up in singly ionized nitrogen, and the N II spectrum dominates the hot phase: multiplets at 399.5, 444.7, and 463–464 nm in the blue–violet, with strong members at 500.5 nm and 568.0 nm [17, 23, 29]. As the channel cools these fade and the hydrogen Balmer series takes over: $\text{H}\alpha$ 656.3 nm peaks tens of microseconds after the current peak and persists longest [17]. The hydrogen is not native to dry air—it is stripped from water vapor dissociated in and around the channel, which is why $\text{H}\alpha$ is conspicuously strong when lightning forms in humid air [17, 21]; the night of August 9 sat at 86–90% surface humidity with drizzle beginning within the half hour. Neutral species matter less to our band: the very strong OI 777.4 nm triplet and NI multiplets in

the 740–870 nm range fall beyond the IR-cut filter, leaving only the weak O I 615.8 nm multiplet inside the passband. In the model the atomic component is a fixed template: Gaussian lines of width $\sigma \simeq 2.5\text{--}3$ nm (slitless-spectrograph scale, standing in for Stark-broadened profiles) with relative energies ordered per Orville [17] and Orville and Henderson [18], H α strongest.

2.4 The molecular bands

The third component is molecular: the N $_2^+$ first-negative system ($B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$), with bandheads at 391.4, 427.8, and 470.9 nm [17, 24]. Exciting it requires ionizing N $_2$ (15.6 eV) and lifting the ion a further ~ 3 eV—conditions met not in the fully dissociated return-stroke core, where little N $_2$ survives, but in the cooler periphery: the corona sheath around the channel, leader and streamer processes, and the recombining afterglow [17, 21]. These are the same bands that color the blue–violet fringe of aurorae, where the 427.8 nm line is the standard photometric reference. Their presence in a time-integrated flash spectrum is therefore expected; what the present measurement adds is a *weight*: the color demands that 12–21% of the visible energy reaching the camera came from this violet system, the range set by the continuum-shape limits of §2.5.

2.5 The mixture model and the fit

We model the time- and stroke-integrated spectral energy distribution as

$$S(\lambda) = w_c \hat{B}_{30\,000\text{K}}(\lambda) + w_a \hat{L}_{\text{atomic}}(\lambda) + w_m \hat{L}_{\text{N}_2^+}(\lambda), \quad w_c + w_a + w_m = 1, \quad (2)$$

each term normalized to unit visible energy, with $\hat{B}$ taken in turn as the Planck and Kramers limit of §2.2. The camera model (§3) converts $S(\lambda)$ to white-balanced linear RGB. Fitting the weights to the two measured ratios of Eq. (1) yields, in the Planck limit,

$$(w_c, w_a, w_m) = (0.22, 0.66, 0.12) \longrightarrow R/G = 1.017, \quad B/G = 1.845, \quad (3)$$

reproducing the observed sky pixel to one digital number: modeled (172, 170, 222) versus measured (172, 170, 223) (Fig. 2). In the Kramers limit the best fit is (0.25, 0.56, 0.19), equally exact. Three structural conclusions survive the (real) degeneracies. First, the molecular fraction is required at $w_m = 0.11\text{--}0.15$ (Planck) to $0.17\text{--}0.21$ (Kramers): atomic lines plus continuum saturate at $B/G \lesssim 1.73$ under daylight balance—indeed an infinitely hot blackbody only reaches $B/G \approx 1.88$ —so the violet molecular bands are required, not decorative, under either continuum. Second, the continuum is bounded, $w_c \lesssim 0.26$ (Planck) to 0.33 (Kramers), consistent with the line-dominated character of time-integrated stroke spectra [17]. Third, the red side is independently diagnostic: $R/G > 1$ cannot be produced by the blue-heavy continuum and requires H α at full literature strength—the wet-air line. Lavender, decomposed: nitrogen’s blue–violet ions and molecules at one end, hydrogen’s red at the other, and the green channel left as the local minimum between them.

A note on counting is owed here. The camera records three numbers, but overall brightness carries no source information (stroke energy, distance, and diffusion losses are unknown), leaving *two* chromatic observables. Against them the frozen-shape model spends two free weights: zero degrees of freedom—a solve, not a fit. Freeing the continuum shape between its physical limits adds a third unknown, and the problem becomes formally under-determined; the w_m bracket above *is* that one-parameter family made explicit. The individual line amplitudes were never fitted at all: ten amplitudes against zero residual degrees of freedom are imported as fixed templates from time-resolved slit spectroscopy [17, 18], where hundreds of spectral channels do the decomposing. Our two ratios only adjudicate the mixture of three frozen templates. The closure test retains power despite zero degrees of freedom because the feasible set is small: no non-negative mixture of these templates, under any continuum limit, can reach (say) $B/G = 2.5$

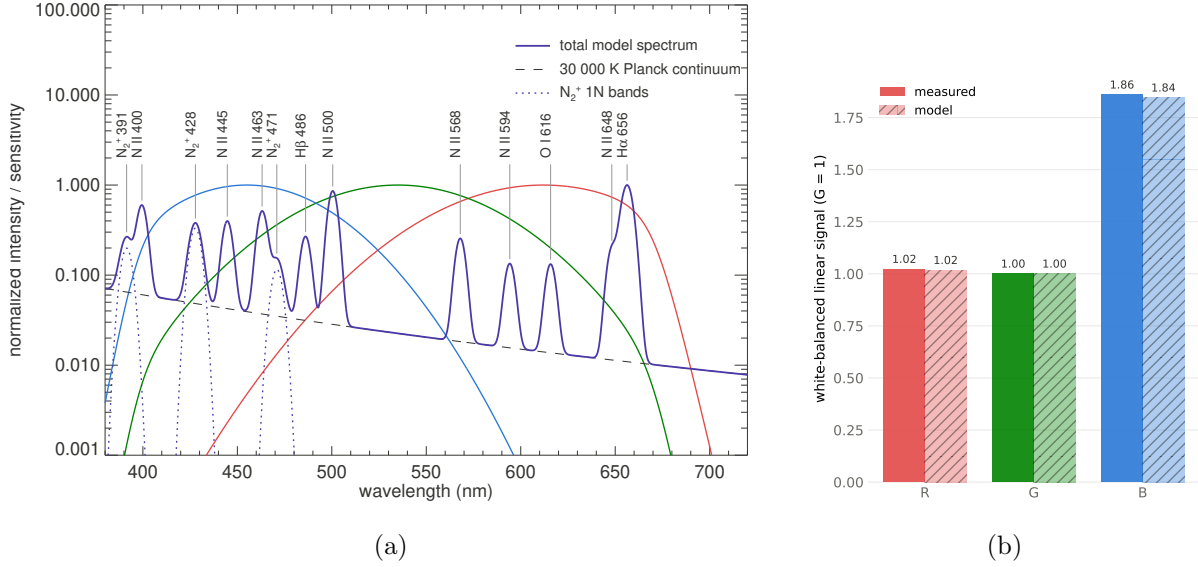


Figure 2: (a) The best-fit emission model on a log–linear scale, with every line labeled: the 30 000 K Planck continuum (dashed), the N_2^+ first-negative component (dotted), and the approximate camera channel sensitivities—red, green, and blue curves—including the 670 nm IR-cut edge (panel drawn in IDL 9.0). (b) Measured versus modeled white-balanced linear color, normalized to $G = 1$.

or $R/G = 1.3$ —the measurement could have landed outside the reachable region and falsified the model. It landed inside.

2.6 Breaking the degeneracy

Three weights against two color ratios leave a one-parameter family: the data cannot distinguish trading continuum against atomic-line energy, because both are broadband compared to the camera channels. The degeneracy is not fundamental, and several escapes are available, in roughly ascending order of effort. (i) *Priors*. Time-resolved spectrophotometry already bounds the continuum share of visible stroke energy at the 10–25% level [17, 18]; adopting that as a prior collapses the family to $w_c \approx 0.15$ –0.25 without new hardware. (ii) *In-scene calibration*. The high-pressure-sodium streetlamps in the same frame have a known, strongly structured spectrum (self-reversed Na D core plus scandium and mercury lines); photographing them—and a reference color chart—through the production pipeline would measure the effective channel curves and color matrix of this specific unit, removing the systematic that currently dominates (§7), and tightening the family. (iii) *A fourth band*. Any additional, spectrally distinct measurement over-determines the mixture: a second camera with different (characterized) sensitivities, or two narrowband filters—one at 427.8 nm for the molecular system, one at 656 nm for $H\alpha$ —turn w_m and the $H\alpha$ amplitude into direct photometry. (iv) *Time resolution*. The components have distinct decay clocks: continuum and $N II$ die in tens of microseconds, $H\alpha$ persists, molecular emission rides the afterglow and any continuing current. Even 1000 fps video—1 ms bins—would separate the hot-phase blend from the afterglow and split w_c from w_a by lever arm on time rather than wavelength. (v) *Ensembles*. Across many flashes at varying (unknown) distances, the emission mixture is approximately common while Rayleigh path-reddening scales with distance; regressing observed colors across an ensemble separates source chromaticity from propagation, calibrating the term we currently assume. (vi) *The grating*. A blazed transmission grating over a spare camera makes the monitor a slitless spectrograph, and one storm’s worth of frames would replace this entire section with a measurement.

3 Engineering: cloud, air, and silicon

Water. The flash reached the camera by diffusion through the overcast deck. Cloud droplets ($\sim 10\ \mu\text{m}$) scatter visible light in the geometric-optics regime with single-scatter albedo ≈ 1 and negligible wavelength dependence; multiple scattering randomizes direction and smears time (by tens of microseconds per kilometer of diffusion path) but is nearly chromatically neutral [4, 12, 26]. Liquid and vapor-phase water absorption in the visible is weak (the red-band overtones are orders of magnitude too small over these path lengths). The deck therefore acts as a large neutral diffuser: it preserves chromaticity while converting a point stroke into hemispheric illumination—and, by admixing multiply-scattered white light, desaturates it, which is why the lavender is pale. We include one chromatic propagation term: Rayleigh extinction over an assumed 3 km effective clear-air path, $\tau(\lambda) = 0.036 (550/\lambda)^4$, a few-percent reddening.

Silicon. The camera (Elgato Facecam 4K, Sony STARVIS 2 sensor) is operated with every automatic control disabled: manual exposure, manual gain, white balance fixed at 5600 K. We model Bayer sensitivities as Gaussians (B: 455/38 nm, G: 535/45 nm, R: 612/48 nm) within the family of measured consumer-camera response functions [10], multiplied by a 670 nm IR-cut and 398 nm UV edge; white-balance gains are defined so a 5600 K Planck source renders neutral. Because the WB is locked, the $\sim 30\,000$ K-class source renders honestly blue instead of being neutralized—the instrumental design choice that makes this measurement possible. Measured JPEG values are linearized with the sRGB transfer function [9] and baseline-subtracted in linear space. The red channel’s retained sensitivity at 656 nm (~ 0.66 of peak) is what lets $\text{H}\alpha$ lift R to parity with G ; a camera with an aggressive 650 nm IR-cut would have rendered this flash noticeably bluer.

4 Meteorology

The synoptic context was a warm, saturated boundary layer: 100% overcast at 2500–3000 m, 86–90% surface humidity, with reanalysis showing drizzle beginning exactly at the top of the hour [8]. No thunderstorm code appears at the grid point—the flash likely came from an isolated convective cell embedded in, or behind, the stratiform deck, of the kind reanalysis routinely smooths away. Three faint blue excursions across 30 minutes suggest a small cell passing at distance. The wet-season signature matters twice over: the humid air fed the $\text{H}\alpha$ line (§2), and the low deck provided the projection screen. The event is also a one-frame advertisement for fixed-exposure urban sky monitoring: a 100 ms exposure every 300 s is a 1-in-3000 duty cycle, yet over a season of nights even rare transients—lightning, fireworks, aurora—will land in frames whose radiometry is interpretable after the fact.

5 N ii, N_2^+ , and the ecosystem: the fertilizer in the spectrum

The nitrogen spectrum of the flash is not just a curiosity; it points at the atmosphere’s strongest natural machine for breaking the $\text{N}\equiv\text{N}$ triple bond. That bond, at 9.8 eV, is why nitrogen—the most abundant element in the atmosphere—is the limiting nutrient of most ecosystems: molecular N_2 is biologically inert until something tears it open. Lightning runs two factories that do, and our one pixel carries a certificate from each.

The first factory is thermal, and its certificate is the *atomic* spectrum. Every N II photon attests that an $\text{N}\equiv\text{N}$ bond was fully broken and the fragment ionized besides—and at $w_a \simeq 0.6$ the dissociation signal is not a garnish on the flash but most of its light. The fixing, however, happens elsewhere, and in the dark. In the $\sim 30\,000$ K core nothing can be kept: nitric oxide formed there re-equilibrates away. It is the 2000–4000 K cooling shell and mixing zone that runs the Zel’dovich chain ($\text{O}_2 + \text{N} \rightleftharpoons \text{NO} + \text{O}$ and its partner reaction), freezing NO out of equilibrium as the gas cools [5, 32]—and that shell is spectroscopically silent: too cool to

excite the visible N II or near-infrared N I lines, while the one low-lying transition of the crucial metastable reagent, the [N I] 520 nm doublet of N(²D), is collisionally quenched at tropospheric density (it is an aurora and nightglow line precisely because it needs near-vacuum). The core that shines does not fix; the shell that fixes does not shine.

The second factory is cold, and it is the one the violet bands advertise. N₂⁺ is an intact molecule—ionization barely weakens the bond (order 2.5, 8.7 eV)—so a 427.8 nm photon certifies ionization, not dissociation. But in cool plasma the dominant fate of N₂⁺ is dissociative recombination, N₂⁺ + e[−] → N + N, branching heavily to the metastable N(²D), whose reaction with O₂ yields NO—the sequence that makes aurorae the nitric-oxide factory of the thermosphere [2, 22]. That pathway operates exactly where our molecular emission originates (the corona sheath, streamers, and recombining afterglow, §2.4), so the violet 12–21% marks a real if minority fixation channel: the opening move of the auroral mechanism, running in the storm’s cold plasma.

The budget belongs to the thermal factory. A single flash fixes of order kilograms of nitrogen; globally, lightning contributes roughly 2–8 Tg N yr^{−1}, several percent of all natural fixation and the dominant source of NO_x in the free troposphere, where it regulates ozone production [5, 25]. Before biological nitrogenase evolved, such abiotic channels were the biosphere’s nitrogen supply; models of the Archaean atmosphere suggest declining CO₂ would have throttled lightning fixation severely enough to constitute a nitrogen crisis for early life [15]. The NO oxidizes to NO₂—observed as column enhancements under storms since Noxon [16]—then to nitric acid, and rains out as nitrate. The drizzle that began nineteen minutes after our frame carried that night’s nitrate down onto the lawns in the image foreground—the same lawns whose green chromatic coordinate this instrument logs daily as a phenology metric. The monitor, in one frame, photographed its own fertilization, and the frame is signed by both factories in their budget order: two-thirds atomic certificate, one-eighth-to-one-fifth violet.

6 Aesthetics and color theory

Lavender is a desaturated purple, and purple is the one hue family with no spectral wavelength: it exists only as a ratio of the spectrum’s two ends against a deficit in the middle, on the line of purples that closes the CIE diagram [31]. That is precisely the spectrum lightning supplies—nitrogen’s violet and hydrogen’s red bracketing a green minimum—which is why lightning has read as violet to observers since long before CCDs, and why daylight-balanced film renders it the same way [14, 23]. Goethe, wrong about mechanism and acute about phenomenology, placed *Purpur* at the summit of his color system: the union of the two intensified poles of his polarity, a color nature produces only under extremity [7]. The lightning spectrum is about as literal an enactment of that figure as physics offers—the two ends of the visible conspiring against the middle.

The frame’s beauty is relational, and here the French tradition earns its keep. Chevreul [6], codifying simultaneous contrast for the Gobelins dyers, showed that complementary colors mutually exalt one another; our archive applies his law diachronically. The flash frame sits in a season of sodium-amber nights (#1c1808); amber and violet-blue are near complements, so the anomalous frame does not merely differ from its neighbors—it negates them, and each makes the other more vivid, the eye carrying the remembered amber into the lavender. Albers [1] made the same point operational: color is never absolute, and the identical pixel triplet pasted into a daylight scene would read as concrete grey. Wittgenstein [30] circles a related puzzle—whatever looks luminous cannot look grey—and our sky obliges: values that would be a dull mauve on paper look radiant solely because the surround is midnight. As for what the photograph *is*: in Barthes’s terms the 5678 rows of the season’s log are *studium*, and the one lavender row is *punctum*, the detail that pierces; his *ça-a-été*—the photograph’s stubborn “that-has-been”—acquires an edge here, because this particular that-has-been lasted 100 ms and was witnessed by no one [3]. Merleau-Ponty [13] held that color is not a property but an

encounter between a lived body and the world; this color was encountered by an apparatus alone, and became a percept only in retrospect, a memory without a rememberer. Kandinsky [11] heard violet as a cooled red, “morbid, extinguished”—the thermodynamic pun is free of charge—and Pastoureau [19] reminds us violet served centuries as *demi-deuil*, half-mourning: for a tenth of a second, the sky over Pittsburgh wore it.

7 Holes in the theory

In decreasing order of concern. (1) *The ISP is not sRGB*. The camera’s onboard pipeline applies a proprietary tone curve and color-correction matrix; linearizing with the sRGB transfer function is an assumption, and a CCM mixes channels post-hoc. The 1-DN agreement should therefore be read as consistency, not precision. (2) *Three weights, two observables*. The continuum–atomic split is unidentified; §2.6 lists the escapes, none of which have yet been implemented. (3) *Channel sensitivities are guessed Gaussians* within the plausible family [10], not measurements of this unit; the H α leverage on R/G depends directly on the assumed red response at 656 nm and the IR-cut edge. (4) *The continuum shape is bracketed, not known*. An earlier version of this paper called the Planck-versus-recombination distinction second order; fitting both limits (§2.5) shows it is first order for the molecular weight (w_m shifts from ~ 0.13 to ~ 0.19) though not for any conclusion. The residual assumptions are that the time-integrated continuum lies between the limits (a mixture of opacity phases does) and that Gaunt factors and series edges smooth out over 100-nm-wide channels [28, 32]. (5) *Line ratios are stroke-phase averages*: a 100 ms exposure integrates hot early emission and the cool afterglow in unknown proportion, and our literature amplitudes are typical, not universal—flash type (intracloud versus cloud-to-ground), with systematically different channel energetics [21], is itself unknown. (6) *The propagation model is thin*: the 3 km Rayleigh path is a guess, and in-cloud diffusion is taken as perfectly neutral. (7) $n = 1$, 8-bit quantization, JPEG compression, and the assumption that the amber baseline adds linearly. Items (1) and (3) could be retired cheaply by the in-scene calibration of §2.6; item (5) invites the grating.

Data. The frame triplet, science log rows, fitting script, and figure code (`fig2a.pro`, IDL 9.0; `lightning_model.py`) are archived with the monitor (`archive_ref/2026-08-09/`, `science.csv`).

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