Existing Lighting Conditions at Princeton's Campus

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Introduction, Context

This report summarizes lighting conditions at Princeton's campus, including i) our data acquisition methods, ii) general light levels (illuminance) through a large number of accurate measurements with multiple devices, iii) lighting in fragile ecosystems within the campus, iv) lighting in otherwise sensitive areas, v) good lighting on the campus, vi) the existing conditions in a broader context, and vii) conclusions.

For context, in our 2025 discussions regarding Princeton's 2025 master lighting plan, we agreed that the Princeton Campus is a mixture of "LZ0", "LZ1" and "LZ2" lighting zones, and we also agreed that to "*preserve the park-like nighttime aesthetics of the campus*[1]", and also for general reasons of sustainability and energy conservation, we should adopt the **lower end of the recommended average illuminance range**. Quoting Tables 1 and 2 from the "Existing Conditions, 2025 March 5" report by HLB, recommended roadway lighting illuminances are 0.3–0.6 foot-candles (FC) for local/interior roadways (which holds for most on-campus roadways), and 0.2–0.9 FC for pedestrian pathways. The lower limits are thus 0.3 FC for roadways and 0.2 FC for pedestrian pathways.

These are broadly consistent with the 2015 master lighting plan values, which, for reference, were 0.4-0.9 FC for roadways and 0.5 FC for pedestrian pathways. The recommended illuminance levels for 2025 dropped with respect to the 2015 numbers.

Regarding sustainability, Princeton's sustainability framework summarizes the status, principles, and future plans. Quoting some relevant parts:

- "*The University has an overarching goal of developing even more of a sustainability ethos on campus*". A very important part of this ethos should be responsible lighting without light pollution.
- "*Princeton recognizes the importance of aligning campus planning and sustainability with its educational mission.*" – indeed, lighting at our campus sets an example for our student population, and thus carries as strong educational component.

Existing conditions in this study were reviewed with the above considerations in the focus. Light trespass, glare, overlighting, are all glaring examples of unsustainable, polluting, wasteful practices. Princeton can not afford having such lighting practices on campus.

[1] Princeton's 2015 master lighting plan

1. Data

Photographs

Photos have been collected from campus lighting between 2011 and 2025. Our library consists of thousands of night photos. An abridged version of the album can be found at this google photo album and at starryprinceton.org. Photographs of light-polluting sources were also contributed by students.

Illuminance levels

Illuminance levels were measured with multiple devices to guarantee reliable and calibrated values.

- The first is a **Klein Tools ET130 Digital Light Meter**, which is a medium-quality device, known for its reliability.
- The second device is a high-end **Latnex LM-50KL photometer** that comes with a factory calibration certificate for the range of 0.01 to 20,000 FC. The factory calibration uses a 2856 K effective temperature source. **It has an accuracy of 3% for 2700-3000K sources**, and an accuracy better than 8% for other typical sources between 1600 K to 5000 K. For warm and blue colors it underestimates the illuminance level, but in general, it is designed to measure illuminance for a wide range of sources, including LEDs and white/yellow incandescent light. The device is cosine angle corrected and is overall quite accurate.
- The third device is the high-precision, low-light **Minolta T-10A**. It measures down to 0.00093 FC with an accuracy of $\pm$ 2% and <6% spectral mismatch to the CIE photopic curve. A cosine error (f^2) of $\leq$ 3% keeps angle and color-related measurement errors negligible. Its wide dynamic range and low noise floor make it very precise below 1 FC, which is particularly important for all sub-foot-candle measurements.
- The fourth device is a **Sekonic C-800-U high-end spectrometer**. This device also measures the spectrum of the incoming light, but because the light is split up into a spectrum (in contrast with measuring integrated light), the low-light sensitivity is slightly inferior to the Minolta or Latnex devices. Integration times are longer, and for illuminance > 0.2 FC, it appears overall very accurate. Note that this device is an updated version of the Sekonic C-700 tool used by HLB lighting.

The light meters were tested in our lab for consistency, and they are measuring illuminance consistent to 10%. The Klein Tool is less accurate and reliable, and does not work well under very low-light conditions. Measurements from the Latnex device are more trustworthy. The Minolta T-10A has superior performance under low-light conditions. The Sekonic C-800 is slightly less sensitive, but provides spectral information. **All four tools were cross-measured against each other under a wide range of lighting conditions, and they are consistent to within 10%. The general error-bars on our measurements in this document are <10%.** The only anomalies are at light levels below 0.2FC, where we trust the Minolta, as it was explicitly designed to be accurate at low light levels.

The light meter was always operated with a fresh battery. Observations were usually taken at new moon or under cloudy skies, although the full moon's contribution is expected to be under 0.02 FC, i.e., negligible when compared to artificial lighting. Our measurements are that of the illuminance, i.e., direct light falling on 1 square foot of horizontal surface, as opposed to luminance, which is the amount of reflected light, and a function of the albedo.

Klein Tools ET130 illuminance meter

Latnex LM-50KL illuminance meter

Minolta T-10A illuminance meter

Sekonic C-800

Sky background measurements

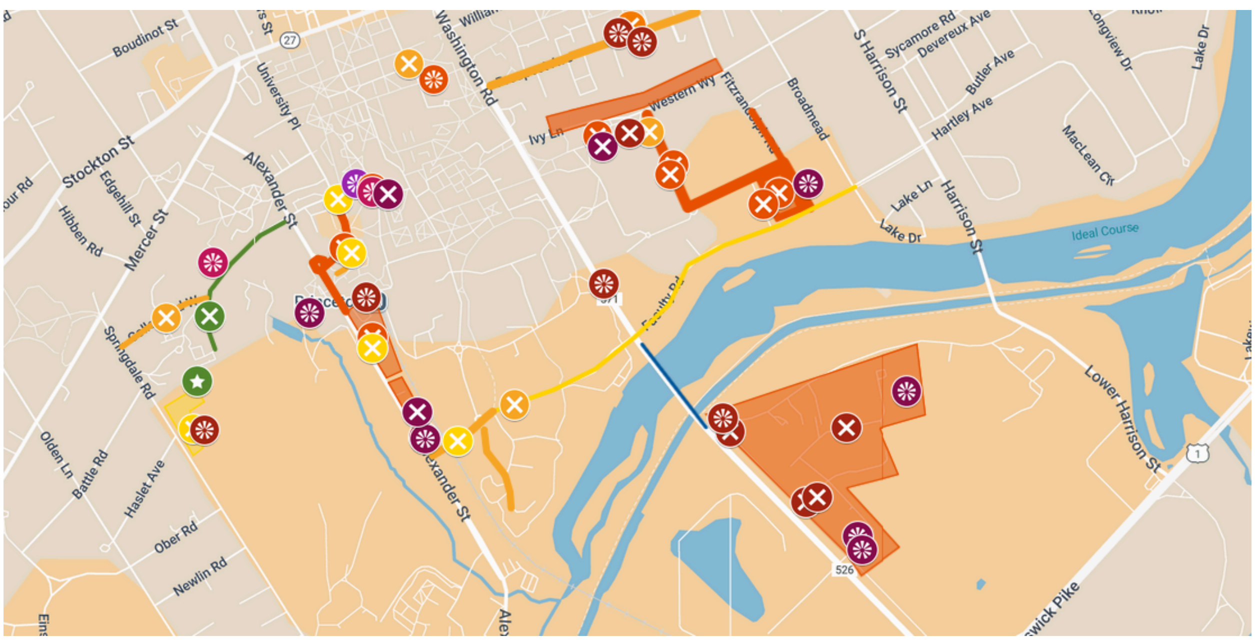
Sky measurements were performed with a Unihedron Sky Quality Meter. Over 14 years, about 5000 measurements were made. (As reported separately, the sky background brightness above Princeton's Campus increased by a factor of 3 between 2016 and 2025). Rhodes Fellow Nicolas Barton wrote his senior thesis on these light pollution measurements.

Aerial images

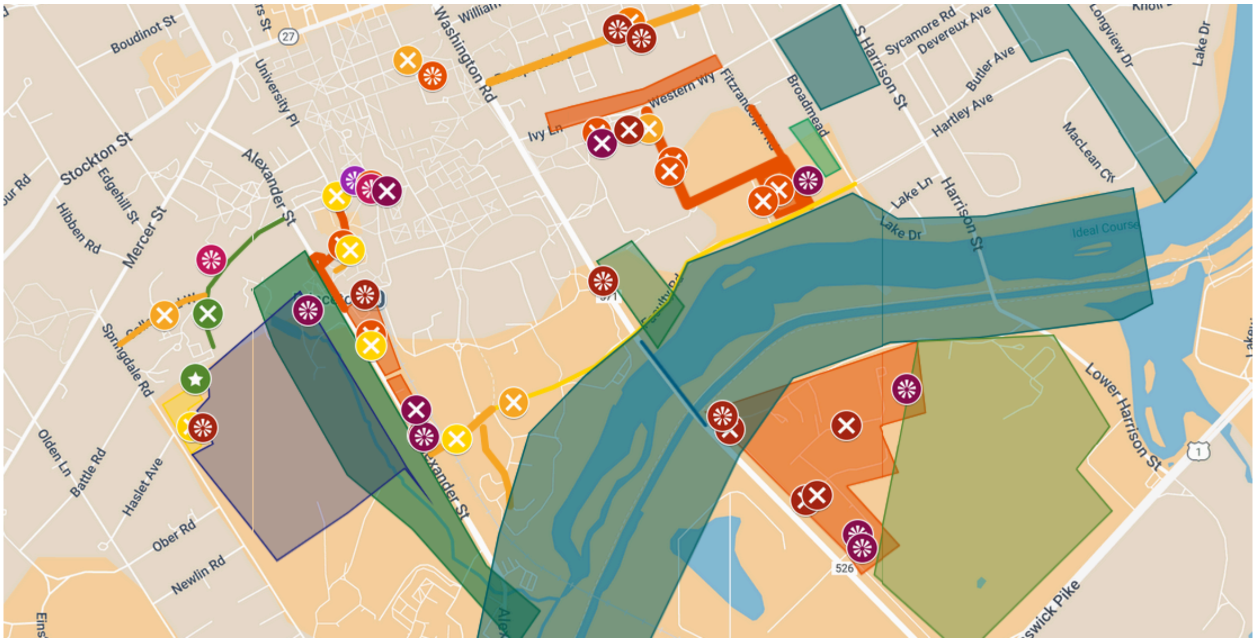
Aerial images were taken from an aircraft in 2016. The aircraft scanned Princeton from above, on a predefined "zig-zag" pattern, encompassing the entire area of the campus. These measurements are available on request. In addition, drone-based measurements were done on the border of the campus, in areas that are far away from the dorms. The drone was typically levitating below 120 meters, following FAA regulations, and was never crossing into any restricted areas. Typical drone locations were: above Lake Carnegie, above the Butler Tracts, and above Harrison Street across Lake Carnegie.

2. Illuminance measurements, general lighting conditions

Illuminance values were measured on 9 separate nights at ~110 locations on campus. Many of the measurements were repeated to check for consistency over time. Also, many measurements were repeated with different light meters, sometimes using multiple meters simultaneously. An overview map of the most relevant and reliable data is shown below. "Crosses" indicate overlit areas. For each area, we provide the maximum illuminance, which is typically under the lamp post, and the minimum illuminance, halfway between the poles. Color coding scales with overlighting from green (good) to yellow (mild overlight) to orange/purple (seriously overlit, on occasions over a factor of 10). Other symbols  indicate areas with significant glare.



Overview of illuminance measurements. Crosses indicate overlit locations, orange shaded areas (other than the map base feature) indicate generally overlit areas. "Firework" symbols indicate glare. The level of overlighting scales with color: blue/green is good, yellow→orange are increasingly overlit. This map is available [on-line]() with all measured values readable from the map, along with images of the area.



Lighting map of Princeton's campus with fragile ecosystems (green/blue) overlaid.

Lighting map of Princeton with designated (or to be designated) dark sky sanctuaries overlaid in blue/purple.

2.1 Stadium Drive Garage

Stadium Drive Garage map. Illuminance is 3.8/1.1 FC (under/between lights). Compare this to the desired 0.3 FC horizontal illuminance for local/interior roadways from Table 12-2 of RP-8-22. The area is overlit by a factor of 3-10x.

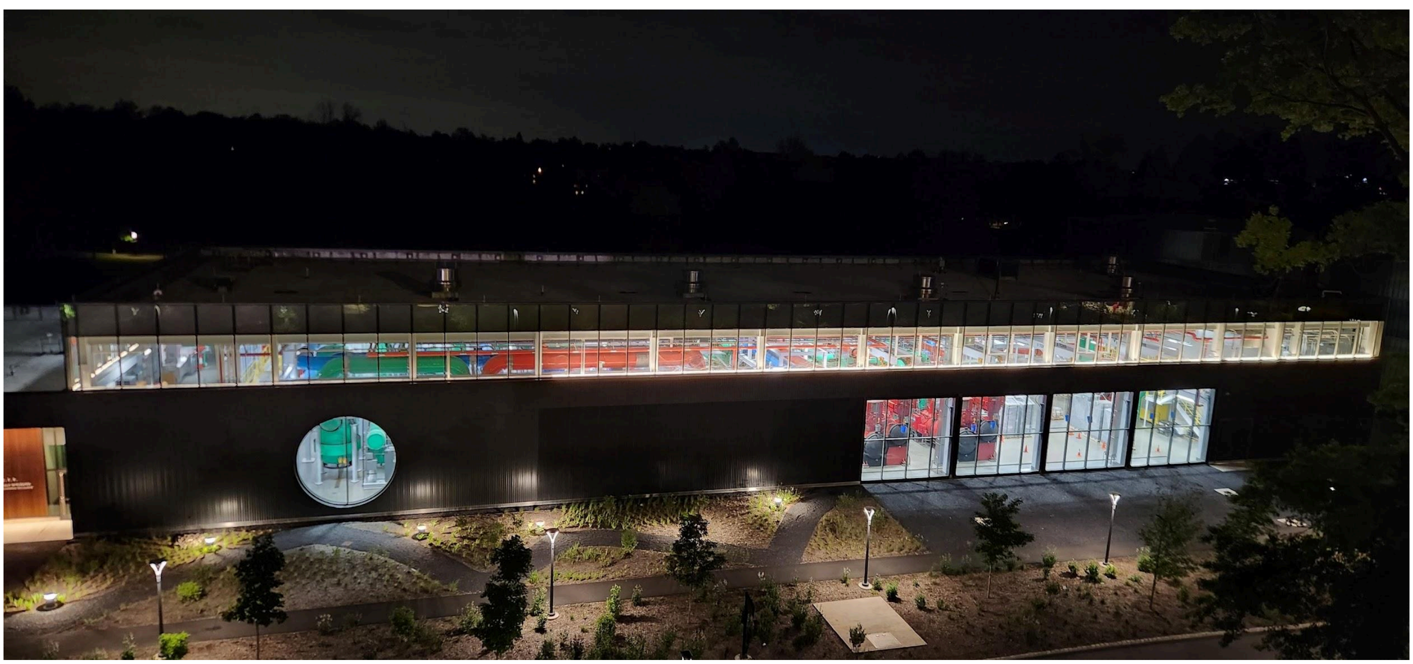
Stadium Drive Garage. Note the very high illuminance with respect to e.g., the pedestrian walkways and the adjacent Faculty Road. The direct illuminance is 2.3 FC. This is independent of the high albedo of the garage.

Light levels were measured under the poles and halfway between the poles. **Under the pole, the horizontal illuminance is 2.3 FC, and in between poles (darkest areas) is 1.6 FC. These values are many times the recommended values for LZ2.** No dimming and no motion sensors control the lights. The amount of light pollution is exacerbated by the reflective concrete, although we stress that the problem is primarily with the overlighting of the surface. The garage roof will be converted to solar panels.

(A) Light measurements beneath & between poles on the walkway near Stadium Garage, 3.08 & 1.16 FC respectively.

(B) Measurements of the horizontal illuminance on the roof of the Stadium Drive Garage, halfway between lamp posts. In this measurement, the light meter was set to "Lux" units, where 1 Lux is approx 0.1 FC; thus, the readings should be divided by 10 to get values in FC.

(B) Roof of Stadium Garage, directly beneath pole, 2.3 FC reading (convert from lux).

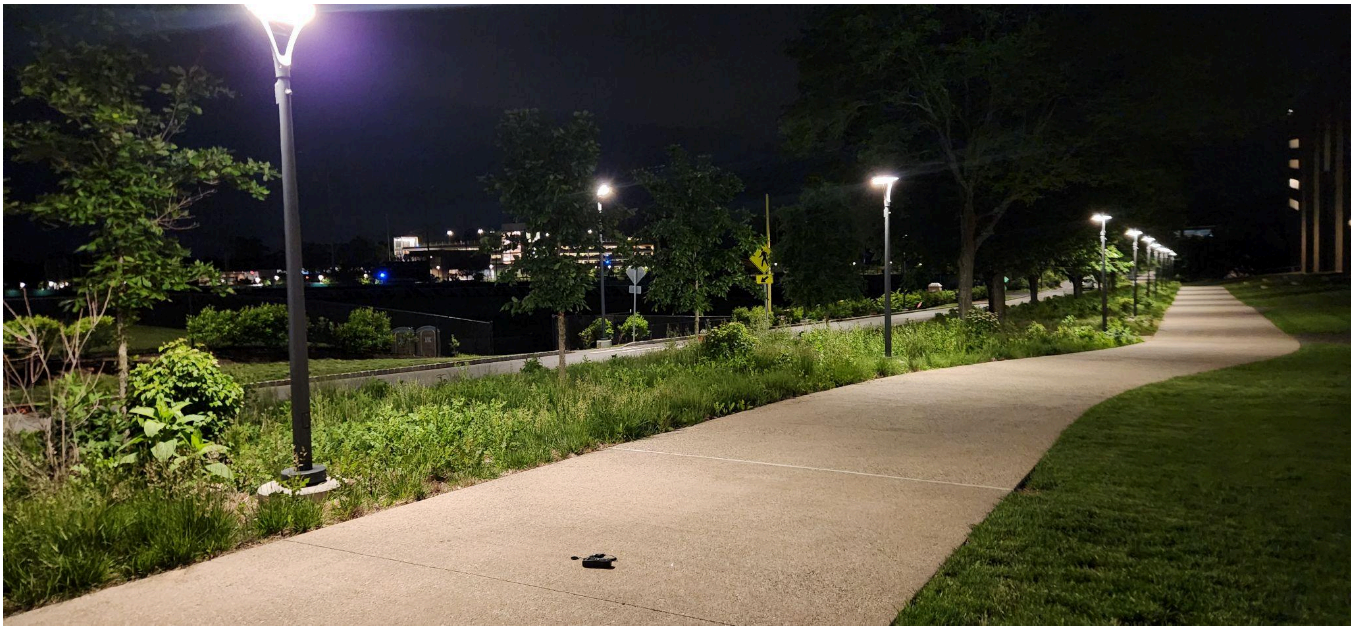


(C) Glare from the geoexchange thermal facility

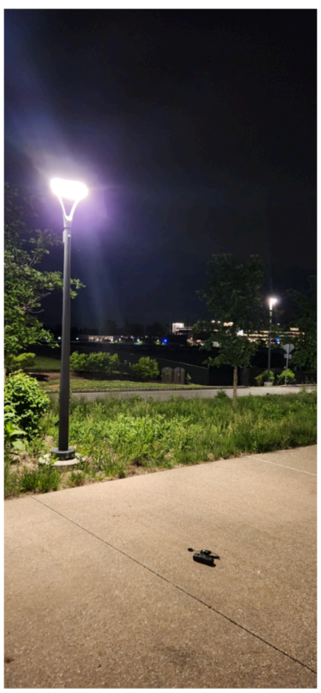
2.2 Stadium Drive Roadway and Pedestrian Walkways

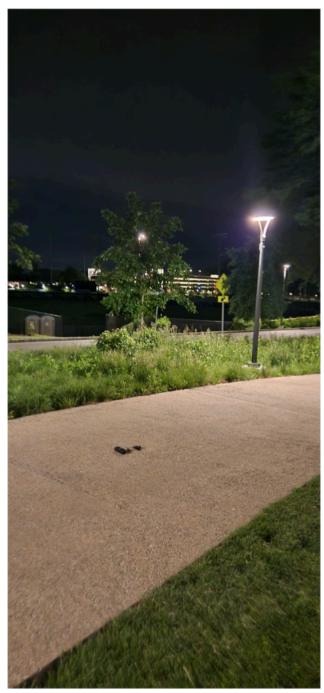
Stadium drive, including both the roadway and the pedestrian pathway received new lighting around 2024. The pedestrian pathway fixtures are BEGA 84121. The roadway fixtures are Bega 99516.

Direct illuminance was measured on multiple nights and at multiple locations. The roadway illuminance is in the range of 0.8 FC (halfway between the poles) to 1.66 FC (under the pole). The pedestrian walkway illuminance is in the range of 1 FC (halfway between poles) to 3.9 FC (under the pole). **These values are many times the recommended LZ1/LZ2 median values; the stadium drive is overlit by a factor of 3 to 10. There are no motion sensors or dimming.** The pedestrian walkway poles are sensor-ready with a provision for a field-installable occupancy sensor, but such sensors were not installed.

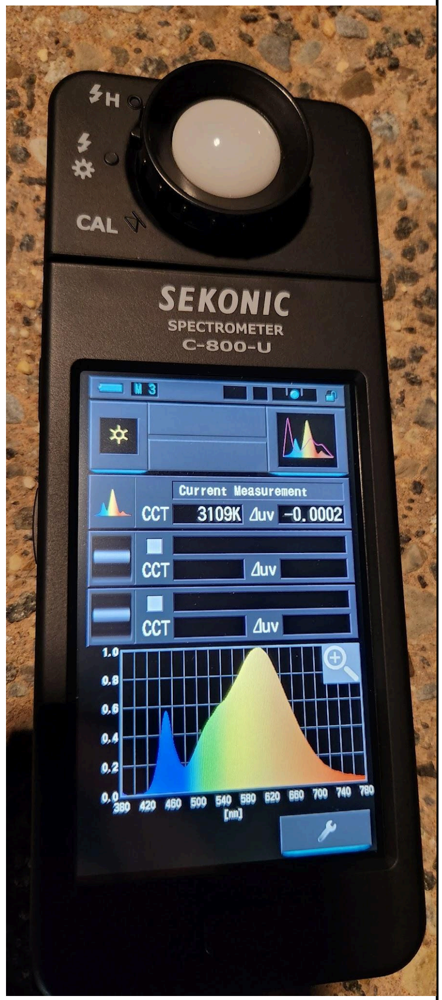


(A) Stadium Drive road and path between Peyton Hall and Stadium Garage. The area is overlit.





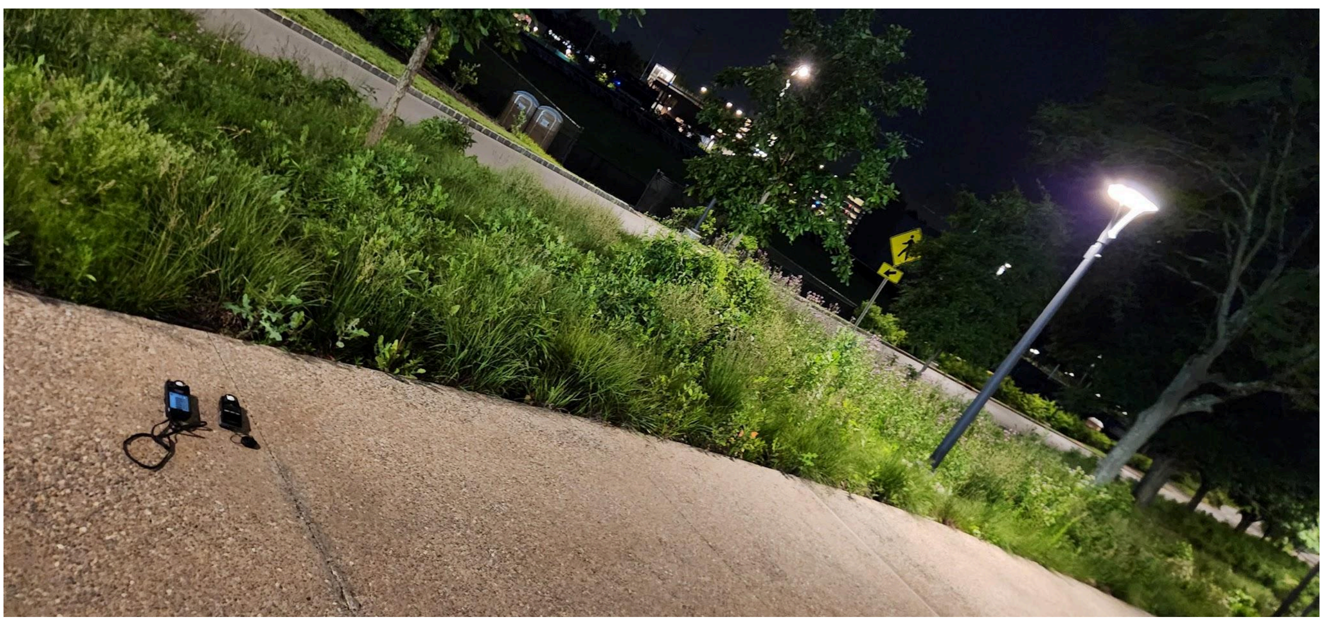
Illuminance measurements on the sidewalk at Stadium Drive, under the fixture, comparing the Sekonic C-800 with the Minolta illuminance meter. The two meters measure illuminance to within 4%.



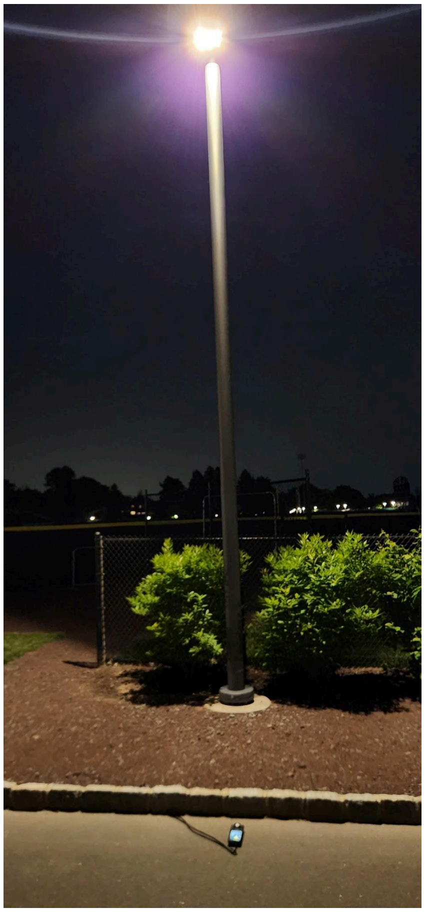
Spectrum of the light at the sidewalk. The overall peak is at 3100K, with a significant (and harmful) blue peak around 400 nm.

The spectrum of the sidewalk illumination peaks at 3100 K.

Illuminance measurements halfway between the sidewalk fixtures, comparing the Sekonic and the Minolta meters. They are consistent to within 5%.

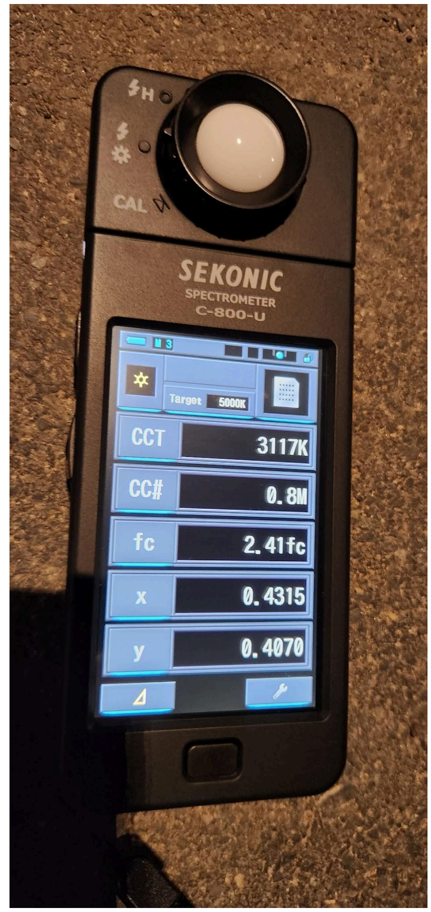


(B) Stadium Drive road between Peyton Hall and Stadium Garage, measurement taken directly under the pole and between poles, 2.39 FC and 0.95 FC, respectively (desired value: 0.3 FC). Independent measurements with the Klein Tools meter were consistent.



Illuminance under the roadway light on Stadium Drive.

Spectrum of the roadway light. Peaks at 590nm, with a significant blue peak at 400nm.

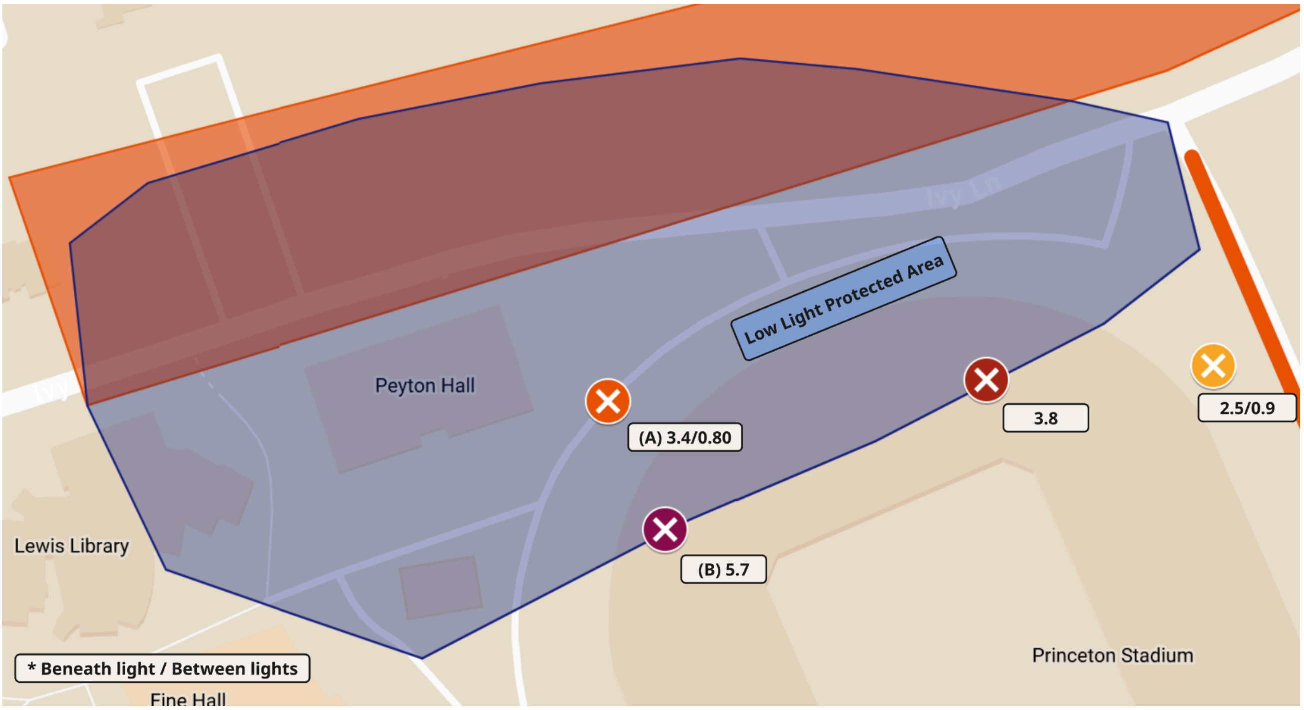


Color temp 3100K, illuminance 2.4 FC

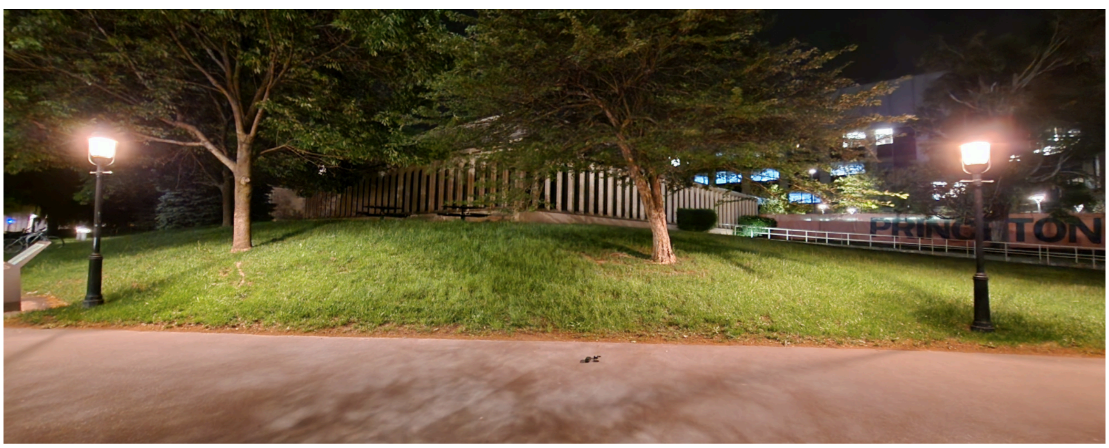
(C) Illuminance measurements on Stadium Drive's walkway under the light fixture. The reading is 3.92 FC; the walkway is overlit by factors of many.

(C) Illuminance measurements on Stadium Drive's walkway, halfway between light fixtures. The reading is 0.98 FC.

2.3 South side of Peyton Hall & Stadium Arch

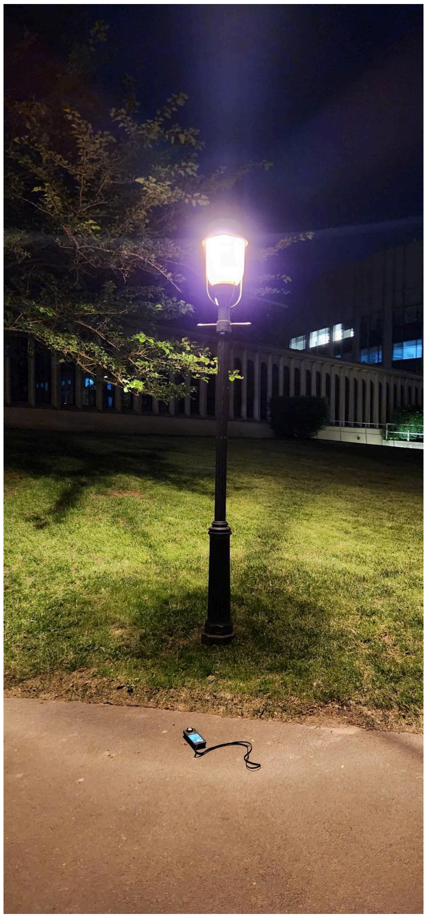


South side of Peyton Hall and Stadium Archway. Measurements found overlighting, as high as 5.7 FC. Some of these lights also directly illuminate the rooftop of Peyton Hall, where AST course observations are conducted. The general reflection of the surface causes a significant excess sky background due to reflection on aerosols.*

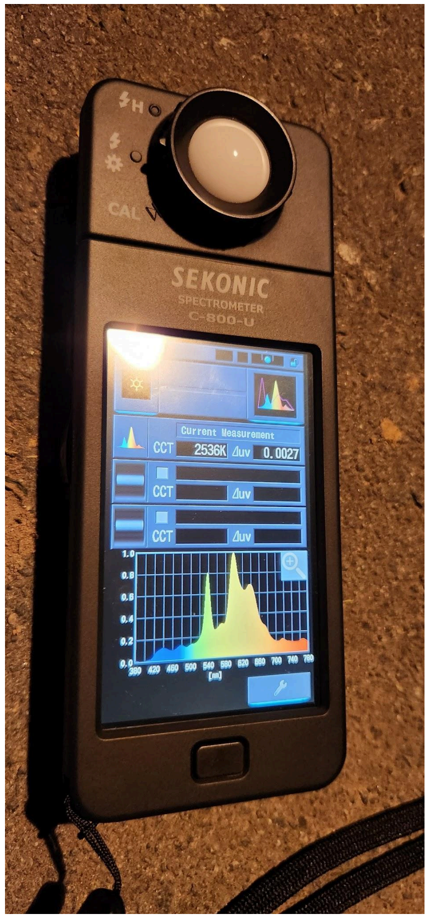


(A) Southside of Peyton Hall, measurement taken between two lamps, 0.89FC reading

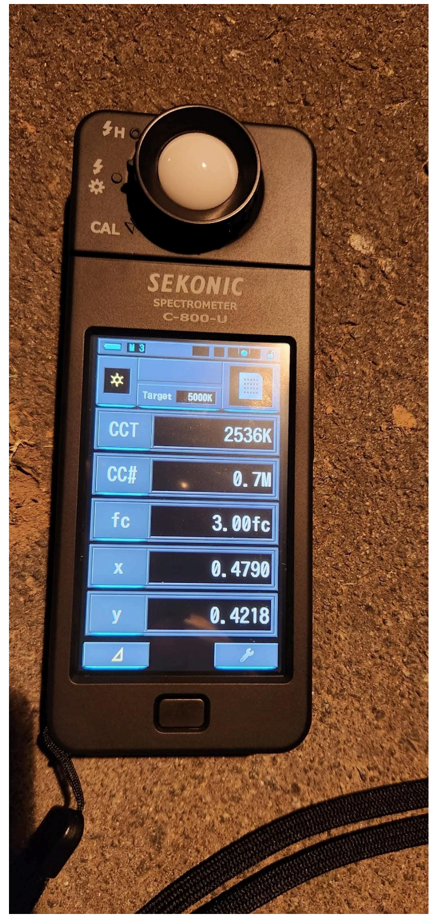
(A) cont. Southside of Peyton Hall, directly beneath the lamp. Measurement of 3.46 FC (target 0.3 FC).



Light measurements under the classic Penn Globe fixtures at Peyton Hall.



Double peaks with 540 and 620nm peak. No blue emission.



Overall illuminance of 3FC under the pole.

(B) Stadium archway, adjacent to Peyton Hall. Measurement of 5.71 FC (desired value 0.3 FC).

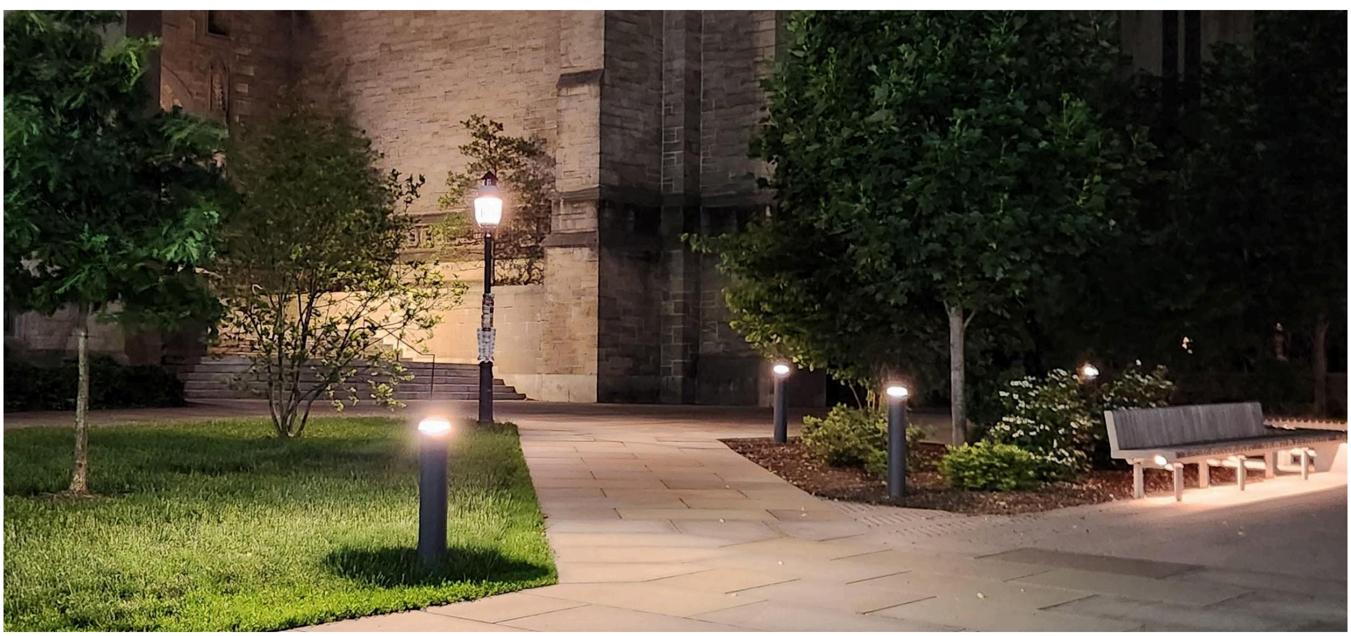
2.4 ES+SEAS and Peyton Hall North side

ES+SEAS and Peyton Hall North Side map. Orange indicates an overlit area. Blue indicates an area where stellar observations happen.

ES+SEAS Front area/park, very overlit with glare/direct light from buildings.

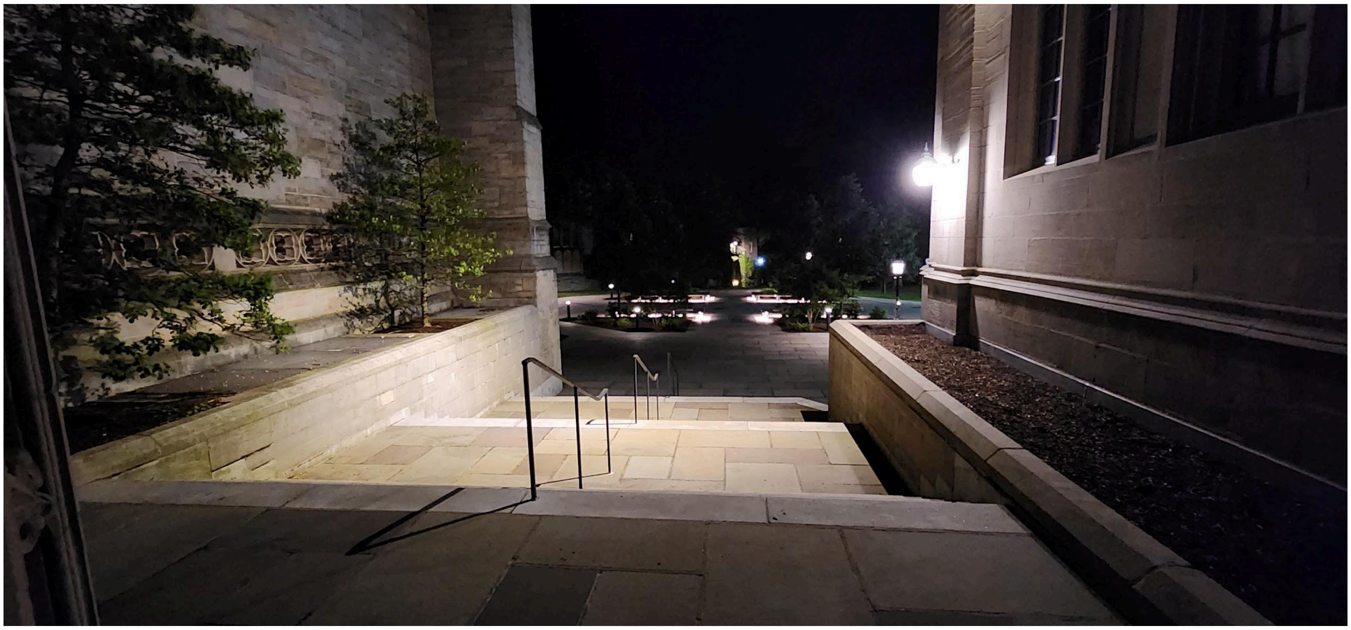
2.5 McCosh Hall and Chapel Plaza

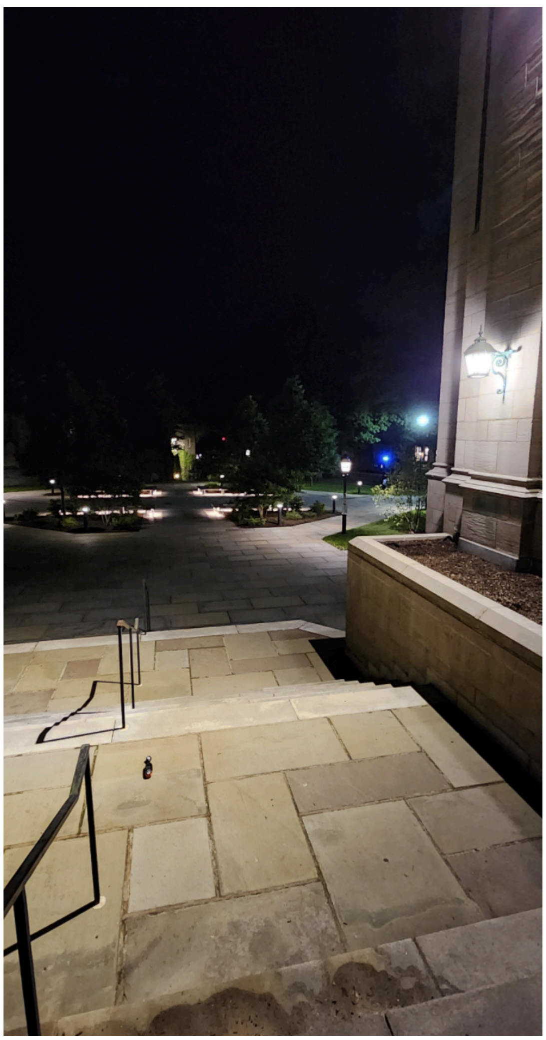
Chapel plaza and McCosh Walk map.



(A) Clusters of unshielded bollards causing glare. The illumination under the benches is aesthetically pleasing, soft, and without glare.

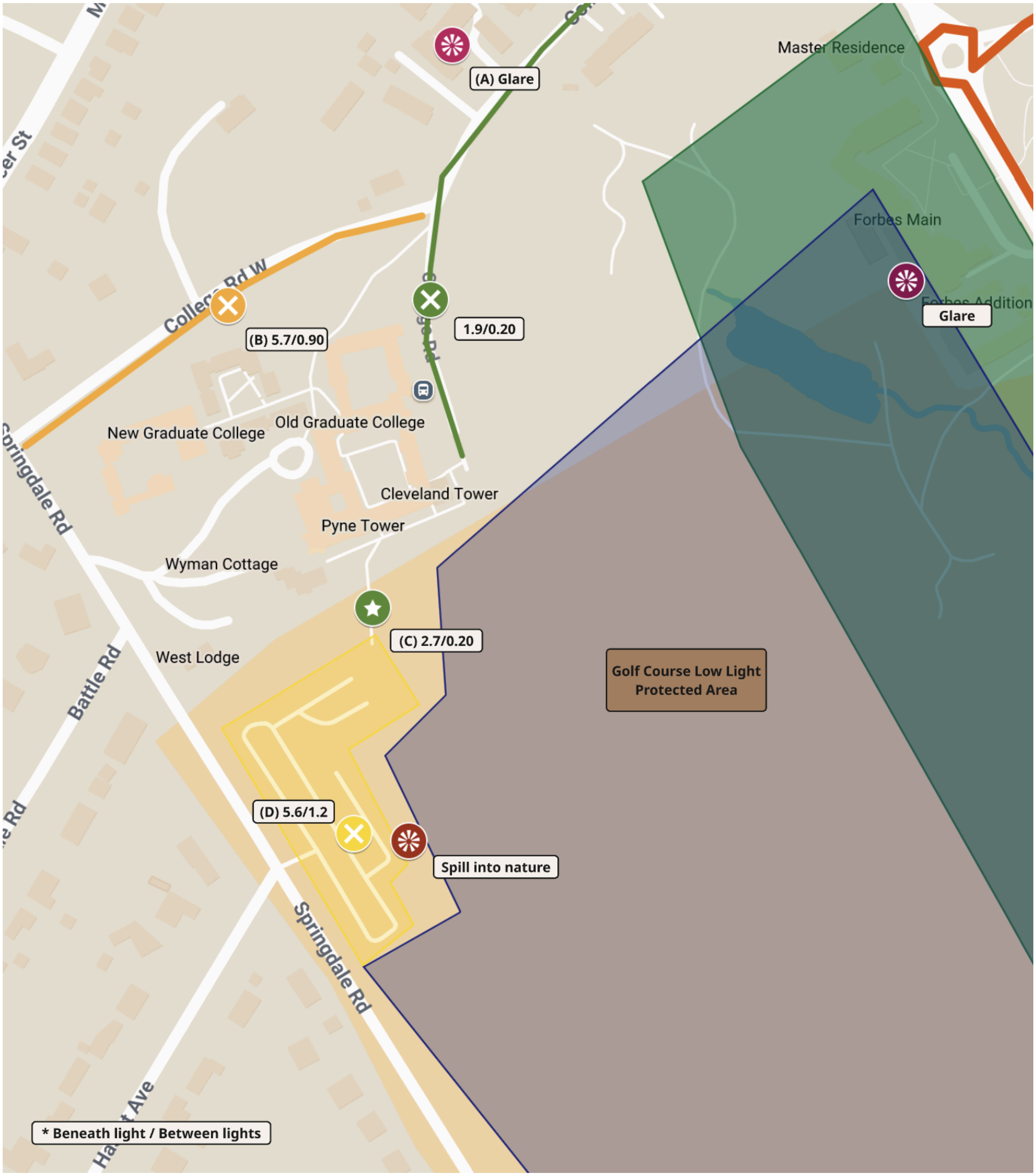
(A) cont. Penn globes, measured at 0.62 FC between poles and 2.28 FC beneath the pole, respectively. (Desired value 0.3 FC).



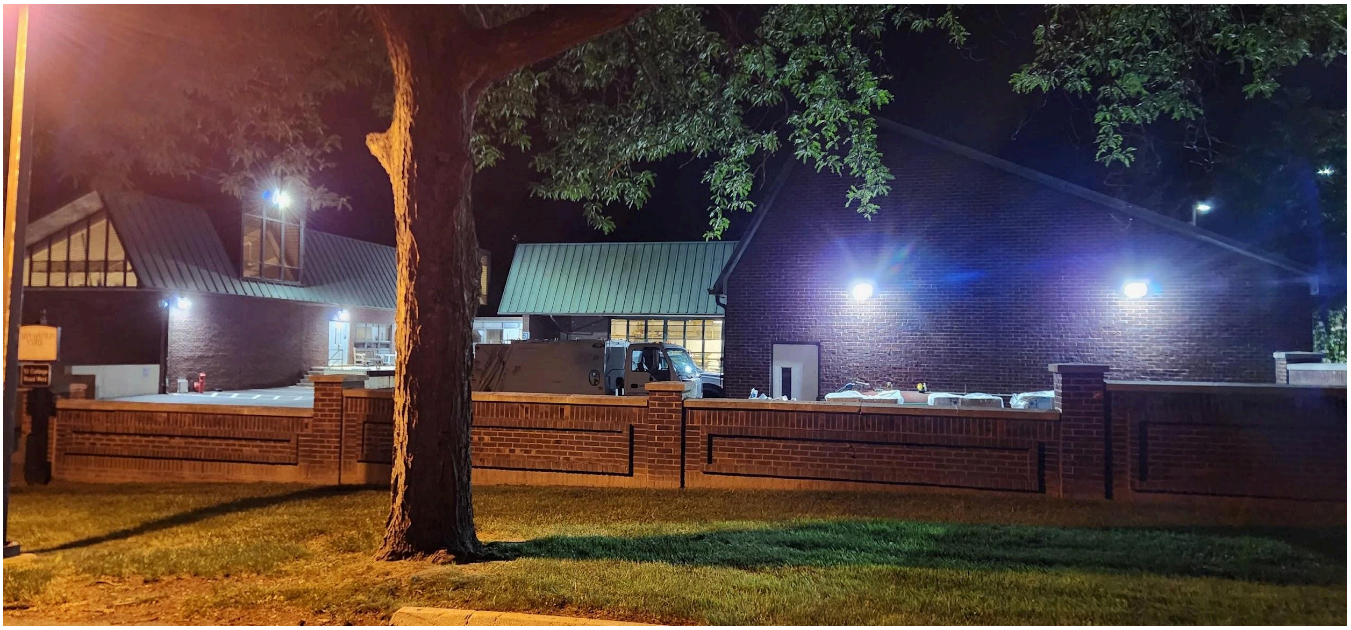


(B) Stairway at the Princeton Chapel. (Desired value 1-2 FC).

2.6 Graduate College and Golf Course



Map of Graduate College and Golf Course. The parking lot illuminance is 5.6/1.2 FC from sodium shoebox lights with some spill onto the golf course, which is a low-light protected area.

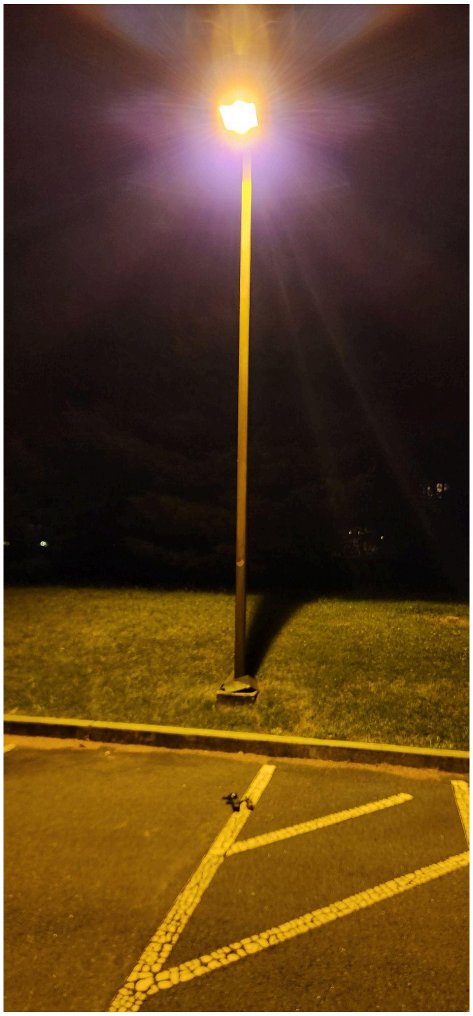


(A) Various facility buildings use area lights, some are almost vertical, unshielded, blue and overly bright, causing significant glare from College Rd.

(B) College road, roadway lighting, sodium, lower estimate. 5.7 FC under post, 0.9 FC between posts. (Desired: 0.3–0.6 FC)

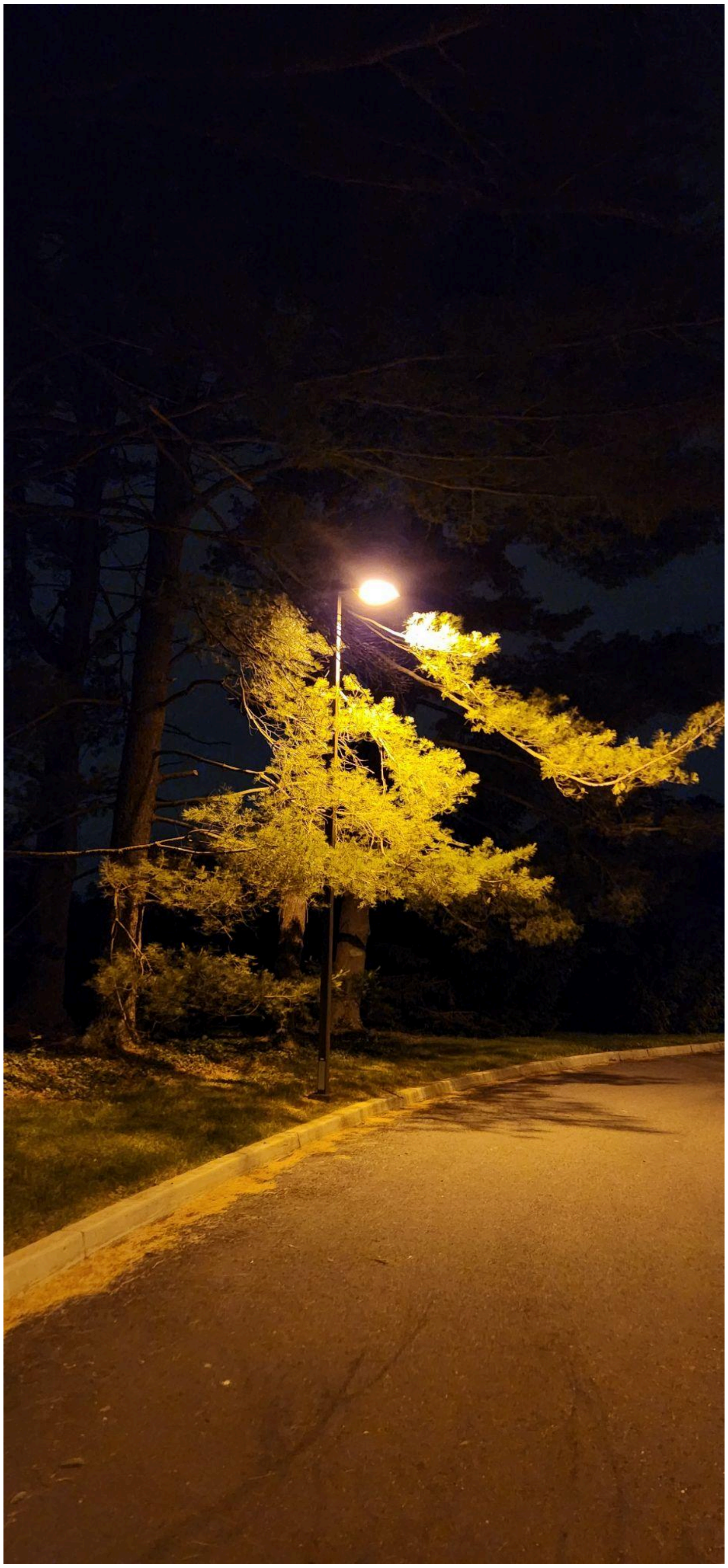
(C) Path from parking lot to graduate college, Penn globes, brighter beneath post, lower but still acceptable limit between posts. Light spills into the nature area. 1.81 FC & 1.66 FC measurements with two different detectors to check for consistency.

(D) Parking lot behind the Graduate College with sodium lights. Measurements underestimate the true value due to sodium. Overall not bad, but a little overlit.



Graduate Parking Lot, 5.63 vs 4.47 FC readings.

Readings of 1.18 and 1.14 FC in the middle of the parking lot, far from the lights. (Desired value 0.3 FC).



Some of the lights in the Graduate Parking Lot are shielded by trees.

2.8 New South Hall to Dinky Station Parking

New South Hall to Dinky Station parking map. Overlit areas are indicated by orange. Areas that should be strongly protected are marked with green.

(A) Shoebox LEDs on high poles. Generally overlit, and the lighting is homogenous due to the high poles. 3.59 FC directly beneath the pole and 2.15 FC between the poles, respectively. (Desired value 0.3 FC).

(B) Overall, slightly overlit area. 2.6 FC directly beneath the pole, 0.47 FC between the poles, respectively. (Desired 0.3 FC).

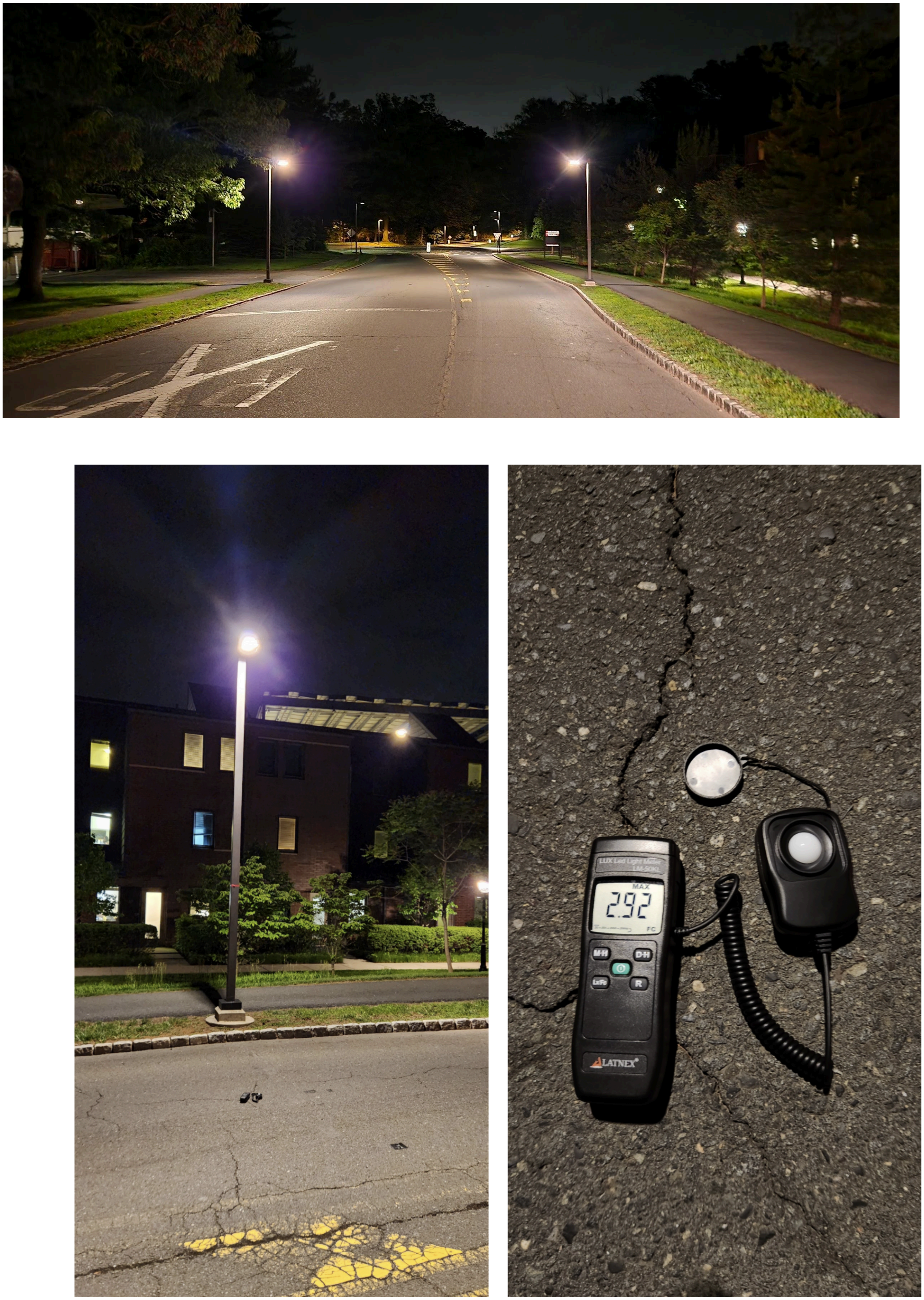
(C) Sharp white glare from a large cluster of unshielded bollards shining directly in the eye, next to Princeton Station.

(D) Dinky parking lot walkway, seriously overlit, 4.55 FC measured.

(E) Dimmest point of the dinky parking lot, point furthest from all poles, 1.1 FC measured.

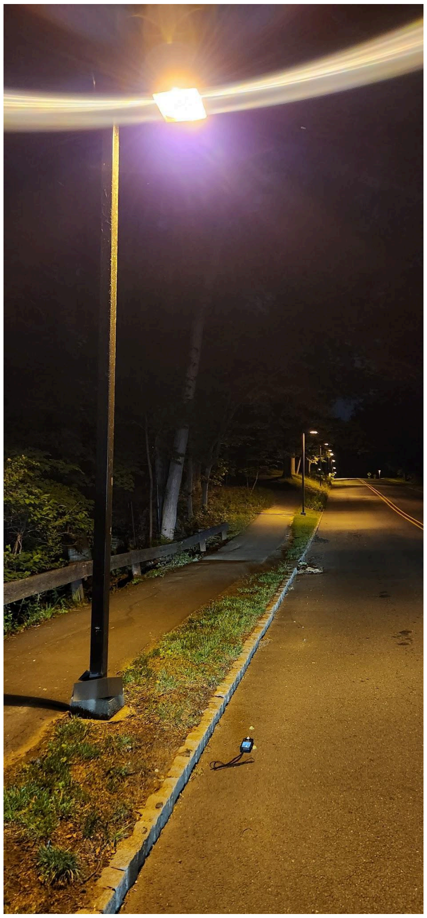
2.9 Faculty Road Near Lake Carnegie and Lakeside Apartments

Faculty Road Near Lake Carnegie and Lakeside Apartments map.

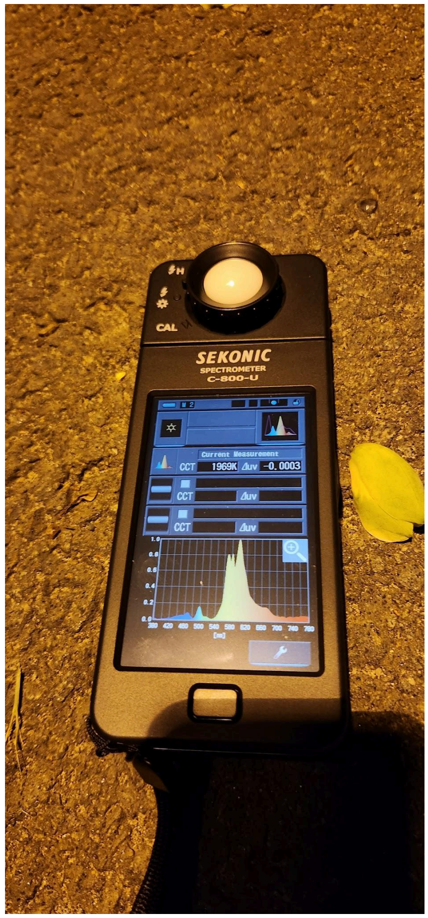


(A) These are low post LEDs with ~3000K light, 2.92 FC directly beneath pole, 1.6 FC between poles at the center of the street. (Desired value 0.3 FC).

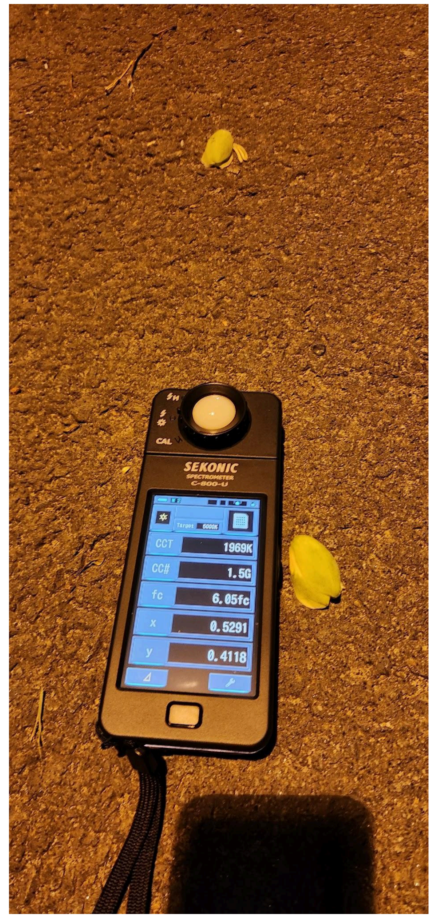
(B) Low post shoebox sodium, very well shielded, slightly overlit. One of the best lighting on campus, even though the backlight is not desirable at other parts of Faculty Rd. Closer to Broadmead. 5.15 FC directly beneath pole, 0.81 FC between poles, respectively.



Illuminance measurements on Faculty Drive under the sodium roadway shoebox lights.



The spectrum peaks around 610nm, corresponding to a color temperature of 1970K.



Lighting level under the fixture is 6FC.

2.10 Pyne Hall to Dillon Gym South Side

Pyne Hall to the South side of Dillon Gym map. Two areas with strong glare are identified.

(A) LED area lights on the wall of the building, some right above the windows of the students.

(B) Strong area lights from the top of the building, causing glare and overlighting, 4.3 FC measured. (Desired value 0.3 FC).

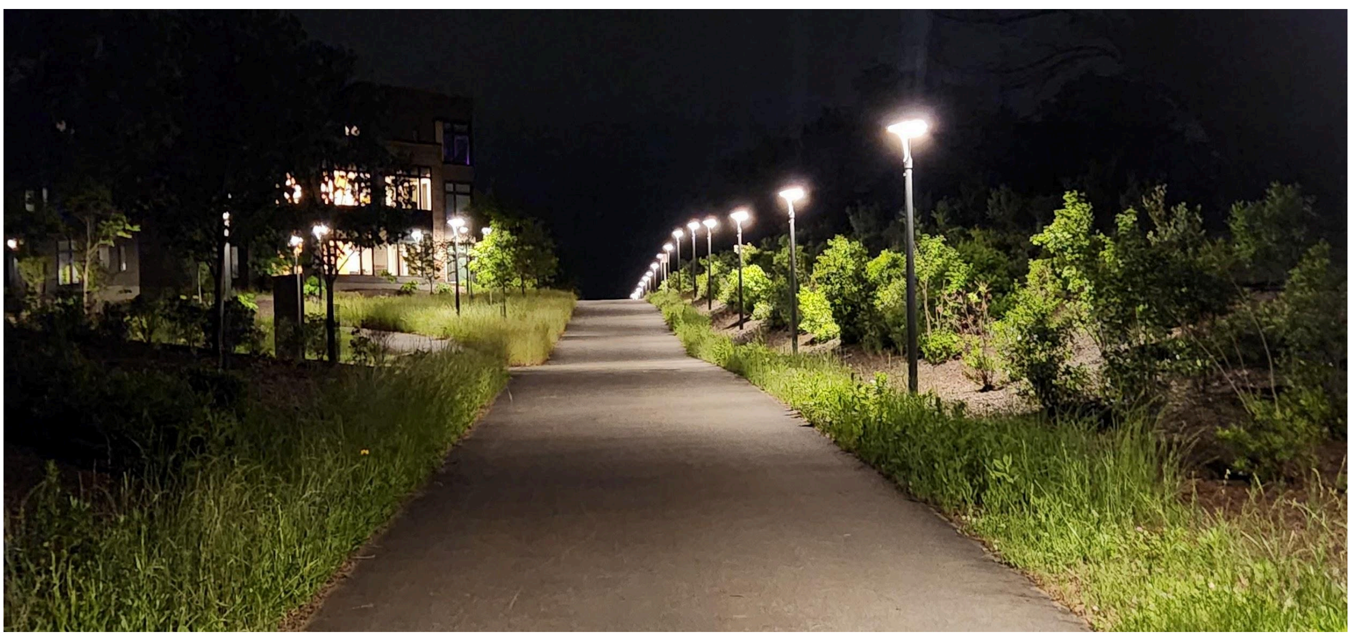
(C) Strong spotlight glare from top of building, majority of light being blocked by top of tree, creating dark patches beneath and blinding passersby.

(D) Makeshift LEDs for the walkway. Extremely bright, causing the loss of dark adaptation for other areas that are ~ 10x less lit, 12.77 FC measured.

2.11 Lake Campus

Lake Campus map. Orange shade indicates the current area of the Lake Campus, all of which is overlit. The area borders the natural area of Lake Carnegie and the Canal Park, and the large open grassland extending to Harrison Street and Route 1.

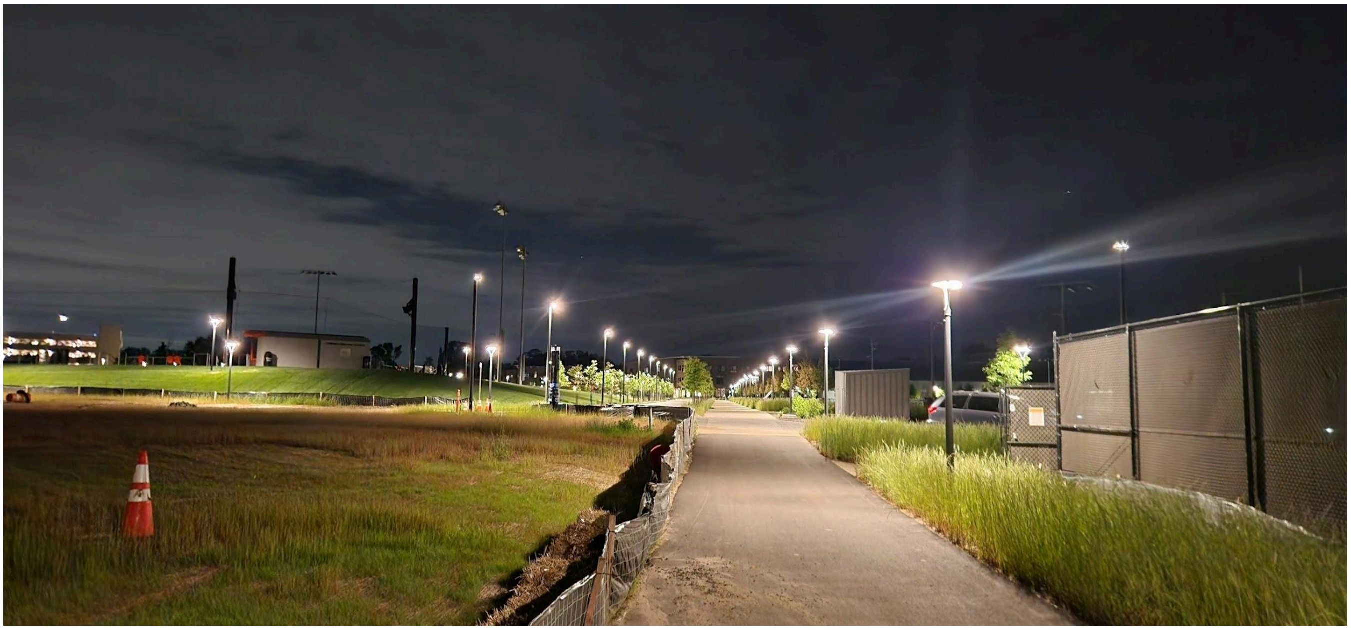
(A) Glare directly into the LZ0 area. Such glare could be avoided with back shielding the Bega 84 fixtures and dimming them.*



(B) Lake campus entrance, generally overlit by factors of many.

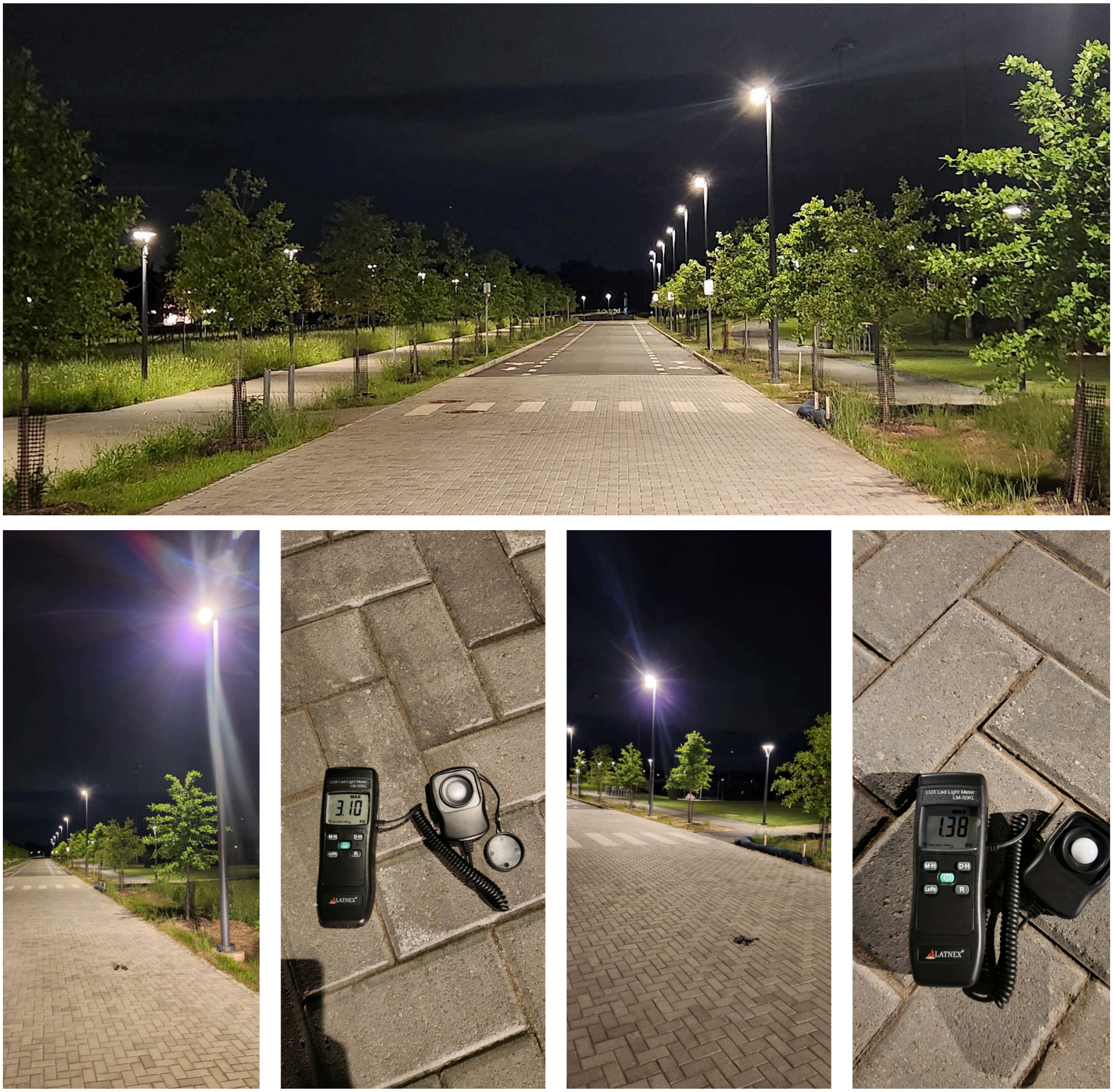
(B) cont. 3.63 FC beneath pole, 0.59 FC between poles, respectively. (Desired: 0.3 FC).

(C) This building at the East edge of the Lake Campus has strong facade illumination all night, flooding the field with light.



(D) Overall glare at the Lake Campus. This entire area used to be a dark field.

(E) The walkway is excessively illuminated, with both roadway and sidewalk fixtures operating at light levels far higher than necessary, 3.47 FC beneath the pole and 1.66 FC between poles, respectively. (Desired 0.3 FC).



(F) Bright white streetlights, overlit by factors of many, 3.10 FC beneath the pole and 1.38 FC between poles, respectively.

(G) Strong, bright lights floodlight the fields from the thermal facility.

(H) The field is illuminated by the thermal facility. A band with a width of hundreds of meters is lit up.

Aerial image of the Lake Campus.

The central alley of the Lake Campus with sidewalk and roadway lights combined, yielding an overlighting of a factor of ~5. Lighting on the edge of the tennis courts with strong vertical light leakage.

2.12 Prospect Avenue (Municipal)

Prospect Avenue map. Note that some of this area is lit by municipal lights.

(B) Municipality sodium globes, 1.30 FC measured.

(C) Bobst Hall, a very bright and blinding area light.

3. Lighting around Fragile Ecosystems

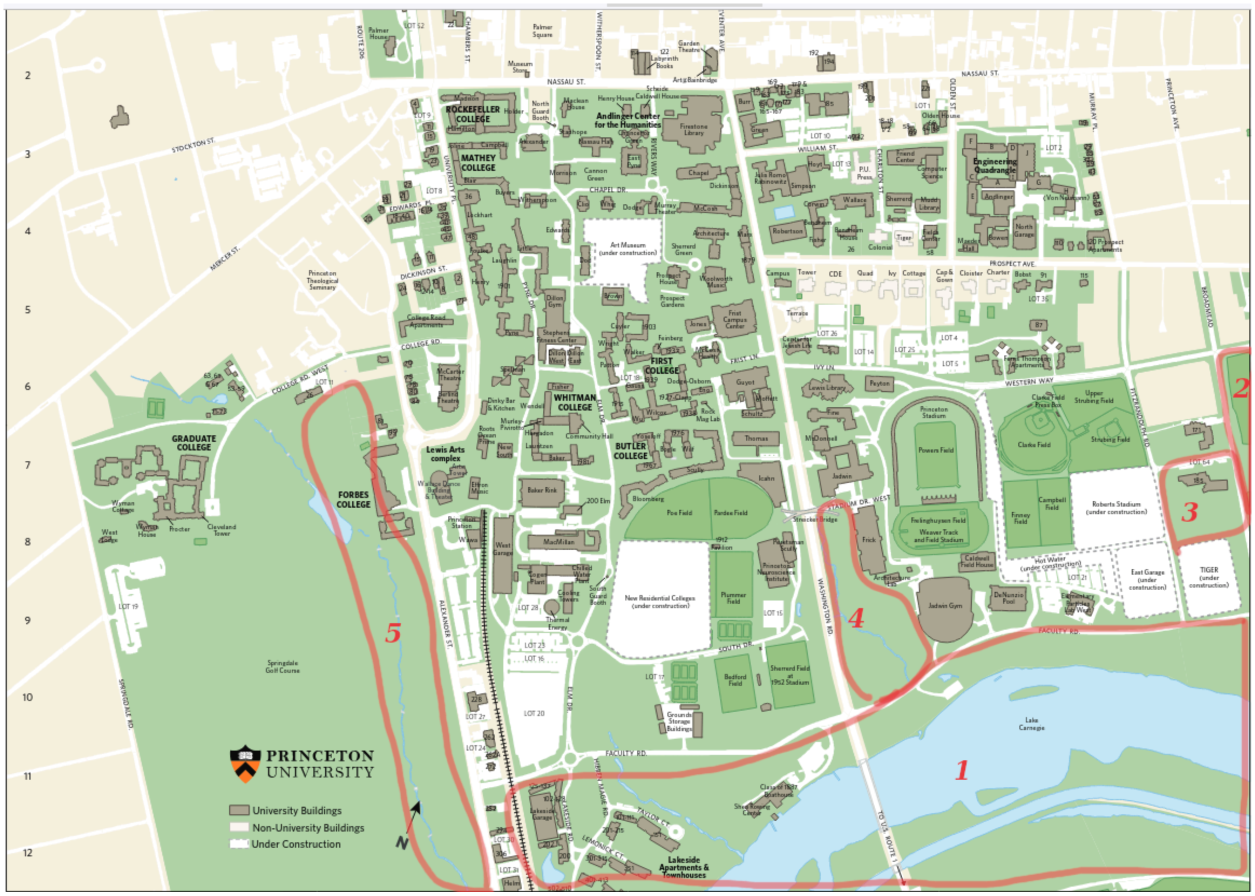
Princeton University's campus contains a number of areas with fragile ecosystems. An overview of the areas hosting such ecosystems can be found at https://www.nj-map.com/blueprint/ecological by zooming in on Princeton, and selecting the "*Ecosystems to Protect 2020*" and "*Habitats for Rare Species*" overlays. Many of these rare species are nocturnal and are highly sensitive to light pollution. A long-term monitoring[2] of Princeton's wildlife revealed a significant population of beavers, river otters, owls, raccoons, foxes, minks, and even a single sighting of a fisher cat. Some of the sightings are collected in this album. Two short documentaries can be found at this video and this video.

There are seven areas within our campus that are protected ecosystems hosting rare species. Given Princeton's commitment to sustainability, we should strive to achieve LZ0 standards, with no stray light entering these areas. Please refer to the figure below for a map.

- Number 1 is Lake Carnegie and its two shores.
- Number 2 is Broadmead (on the right side).
- Number 3 is the shrinking area between the geoexchange facility and Unow.
- Number 4 is the area NE of the intersection of Faculty Road and Washington Road.
- Number 5 is the Golf Course, primarily its East side.
- Number 6 is the area NE of Washington Road and N of Route 1, including the Schenck Covenhoven Cemetery (this area is not marked up in the following classic campus map, but is marked in the njmap).

[2] Wildlife monitoring at Princeton's campus over the course of 2 years, using 15 trap cameras, yielded over 30,000 videos of mostly nocturnal wildlife, and led to a thesis work. The monitoring and the documentaries were supported by the Office of Sustainability.

- Number 7 is the “back side” (East) of the Butler tracts.
- (Number 8 was the area of the current Lake Campus dorms).



Some of Princeton’s fragile ecosystem areas. Marked up are those that are within our standard campus map.

Princeton's fragile ecosystems from njmap.com. Overlaid are the "Ecosystems to Protect" and the "Habitats for Rare Species". This shows all seven "fragile ecosystem" areas.

Area 1, Lake Carnegie, N and S side

Significant light spill into this area is from the following sources:

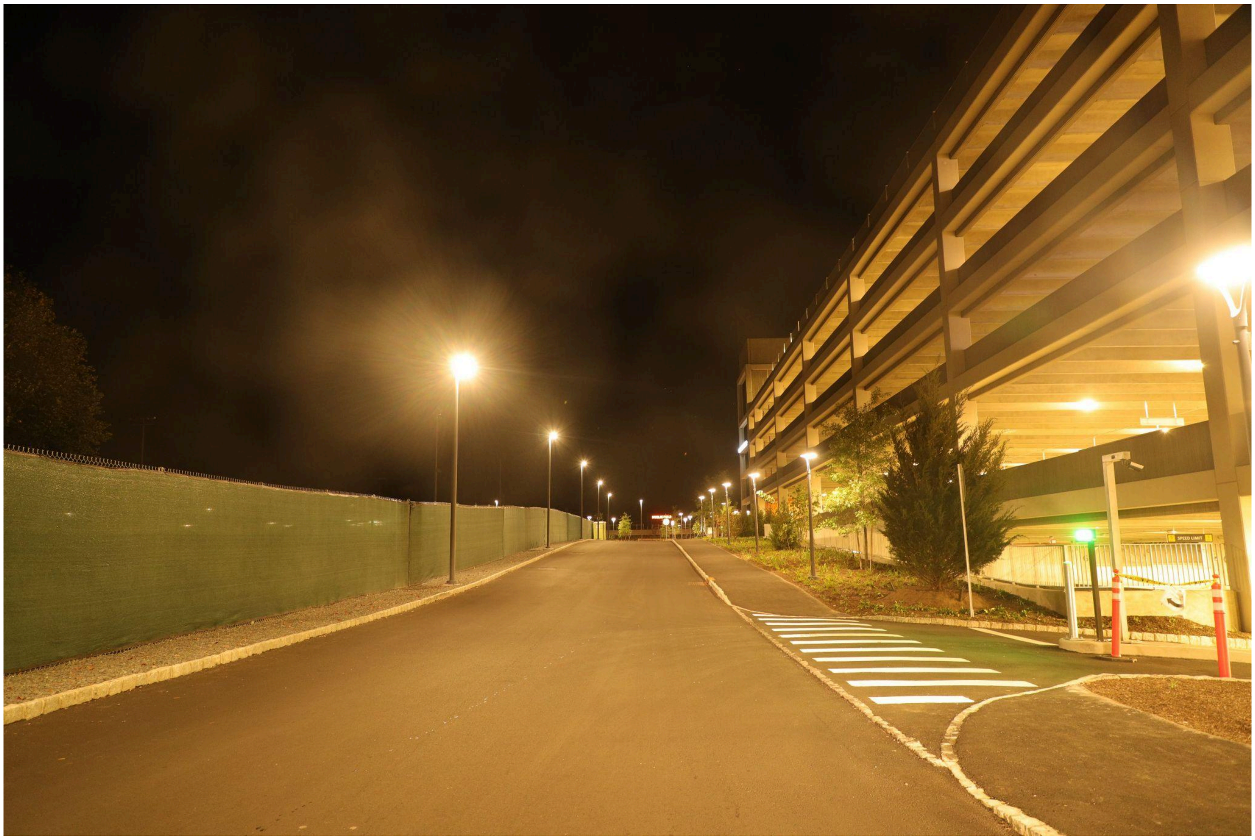
- Faculty drive "shoebox" sodium lights with significant backlight entering the woodlands.
- Geoexchange building internal floodlighting on top with glass.
- Boathouse (to a lesser extent).
- New pedestrian lights on the N edge of the Lake Campus area.
- Uncontrolled "always on" lights from floors 1 through 4 of the Stadium Drive Garage.

Faculty drive with sodium shoebox lights. Note the spill in the woods (toward the bottom left side, which is the lakeside).

Lights from the geoexchange building from the direction of the lakeside woods (Faculty drive). These lights are on all night, extremely bright and blue, 30-40% of the emission going straight up in the sky, another fraction spilling into the lakeside woods.

The boathouse at night from Washington Rd. bridge.

Stadium drive garage and its light spill to Lake Carnegie's woods. This image was taken by a drone, not showing the effect in its entirety. The light spill, as seen from the wood,s is much stronger.



Overlighting and > BUG-0-0-0 fixtures on Stadium Drive spill light in the lakeside woods. See the next image.

The lakeside woods as illuminated by the lights of Stadium Drive. The standard sodium shoebox streetlight was off during the exposure.

Area 2, Broadmead

Broadmead is a relatively dark field, part of Princeton's fragile ecosystems. It has been regularly used for night time star observing. Penn style globes with nonzero BUG rating and the Unow Nursery school spill light onto the field.

Broadmead with light spill from Broadmead st and Western Way and the Unow nursery.

The Unow kindergarten at midnight on an average day. The strong lights spill over to Broadmead.

Area 3, between Geoexchange and Unow

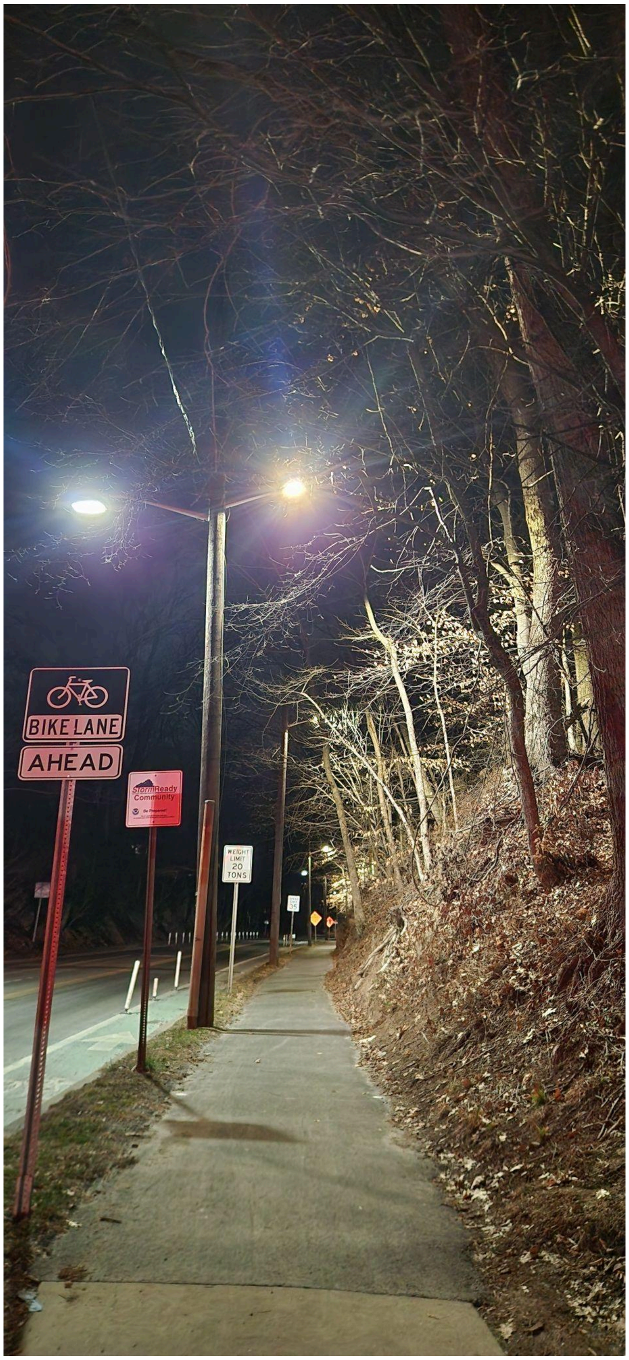
The area between the Geoexchange building and Unow. This ecosystem is essentially lost due to the light spill from the two facilities. This nighttime image demonstrates the very sparse township-cobrahead lights with their blue color, the whiter color from the Penn globe lights, the Unow spill, and a crossing deer.

Backlights from the geoexchange building spill over to the Broadmead/Unow ecosystem.

Area 4, East side of Washington

This is a wooded area with a small creek flowing into Lake Carnegie. It is marked as a fragile ecosystem on the ecosystem maps. I tested this by monitoring the wildlife over 2 years with 2 trailcams, and I can confirm the large abundance of wildlife even in this small area. Spottings included mink, raccoons, deer, foxes, owls, and many others. Recently, inclined “area light” style lighting was installed on Washington Street with a ~30-degree angle, causing a huge spill of light into the woods. Essentially, the entire area became lit up.

The wooded area on the East side of Washington Road, now lit up by poorly positioned area lights.



The area lights that floodlight the woods. The intention was probably to illuminate the walkway.

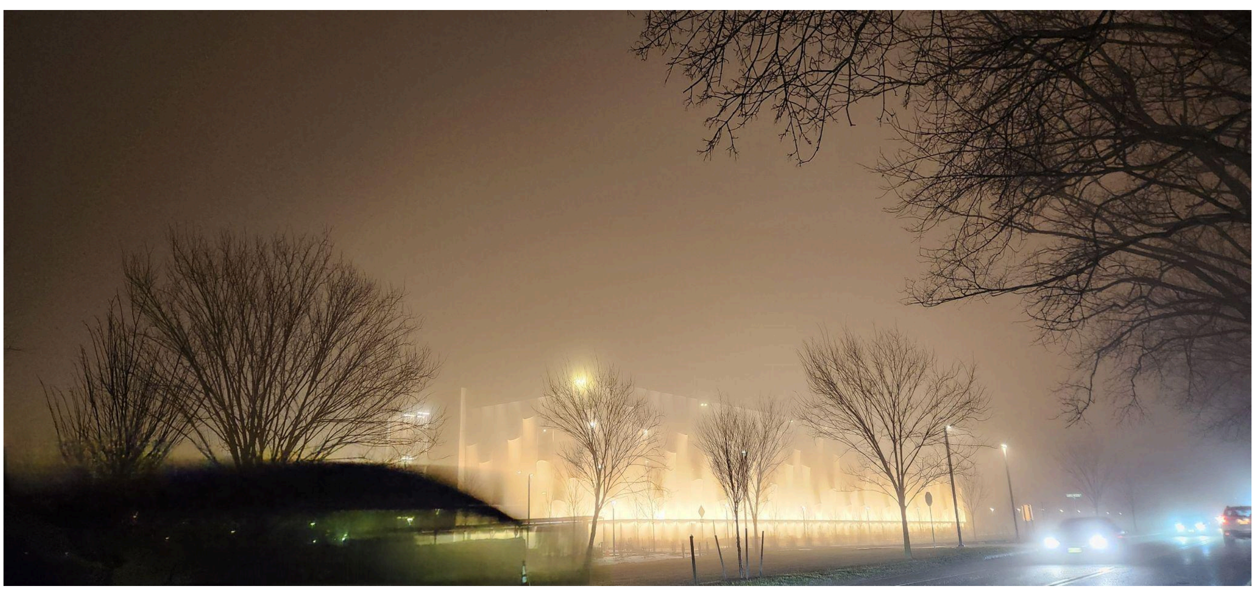
Area 5, Golf Course, Forbes

The golf course behind Forbes and the back (W) side of Forbes are sensitive ecosystems. They were one of the last remaining areas with no direct lights until the back of Forbes received bright, unshielded LED lighting. The undergraduate students and the residential graduate students requested that these lights be turned off, but as of this writing, they are on all night.

Light spills onto the golf course from two extremely bright and unshielded LED lights.

Area 6, Lake Campus

Construction of the Lake Campus was recently finished in this area. A significant fraction of the area remains open, such as the South side all the way to Route 1, including the old Schenck-Couwenhoven cemetery. The area is generally overlit by a factor of 2-5 (with respect to a target of 0.5 FC), and there is significant light spill from the facade of the Lake Campus Parking Garage. The top floor of the garage is also spilling light in the area, but this will be converted to solar panels, hopefully with zero lighting.



Lake Campus Parking Garage and area from the North, approaching on Washington Rd. The garage facade lighting has been dimmed since, and conditions improved (thanks to Dan Casey for his action and update).

Lake Campus area from the south, approaching from Washington Rd. The facade has been dimmed since.

Light glow from the Lake Campus area, as seen from the other side of Lake Carnegie.

Area 7, Butler Tract

This area used to be graduate student housing, but the houses were removed, and the area converted back into a park. The lighting in this area is dominantly with sodium cobraheads. One side of this area is part of the fragile ecosystem. There is no vehicular traffic. There are no Princeton students visiting this remote area. The only traffic is by pedestrians from the local neighborhood. The area is overlit and is constantly lit.

The Butler Tracts at night. Note the strong sodium lighting with the exception of a blue municipality cobrahead in the back.

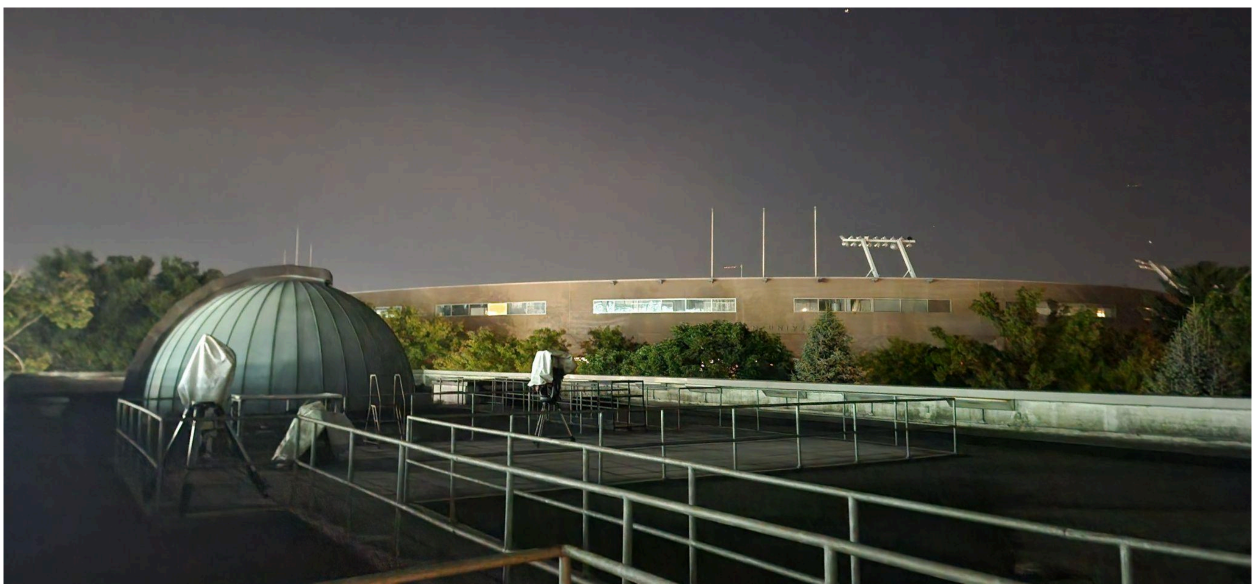
4. Lighting in Other Sensitive Areas

Map of fragile ecosystems (green) and sensitive areas (blue/purple).

Peyton Hall[3]

Peyton Hall is the home of the Department of Astrophysical Sciences. Facilities include the 12-inch Schmidt Cassegrain telescope in the rooftop dome and the roof observing terrace. The **permanent telescope** hosts public observing nights for the Princeton community. In addition, in about 5-10 nights per month, students in the various AST* classes are involved in relevant star, planet, and celestial object observing projects, oftentimes as part of their grade. The **rooftop terrace** is used about 5-10 nights per month for wider-angle observing, such as studying constellations, learning about celestial navigation, using portable telescopes, and naked eye observations.

The rooftop receives direct light from an increasing number of sources. In 2011 the roof was nearly dark; today it is illuminated so brightly that teaching and observing will soon have to stop. The sky background above Peyton Hall is also very bright, a significant fraction of that brightness coming from local sources; either overlighting or lack of proper shielding. These, altogether, debilitate our mission of education and outreach.



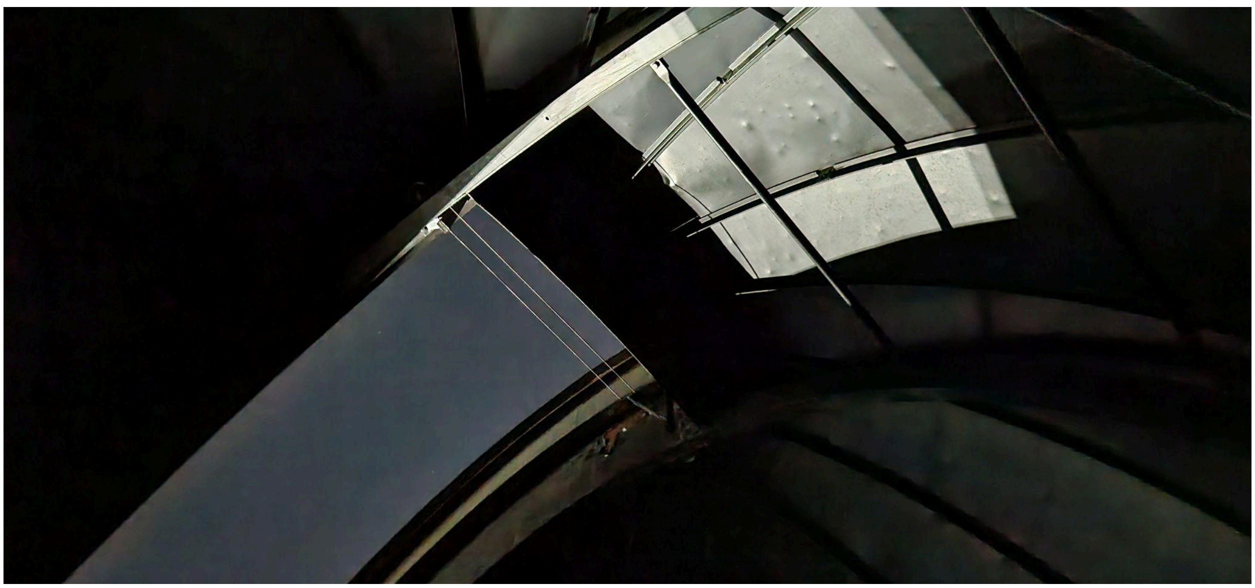
The rooftop observing terrace of Peyton Hall, bathing in strong illumination by the nearby ES+SEAS building. Stadium lights and area lights were turned off when this photo was taken.

[3] Note that this area is described by another document, and the conditions were discussed with Prof. McCoy's team.

The Peyton dome is lit from the side by light pollution.

Stadium archway lights are oriented in the direction of Peyton Hall, disabling any telescopic observation. (The student in the picture is pretending to look through the telescope for reasons of demonstration).

Unshielded area lights directly illuminate the roof.



Lights inside the Peyton telescope dome.

Golf Course and Graduate College

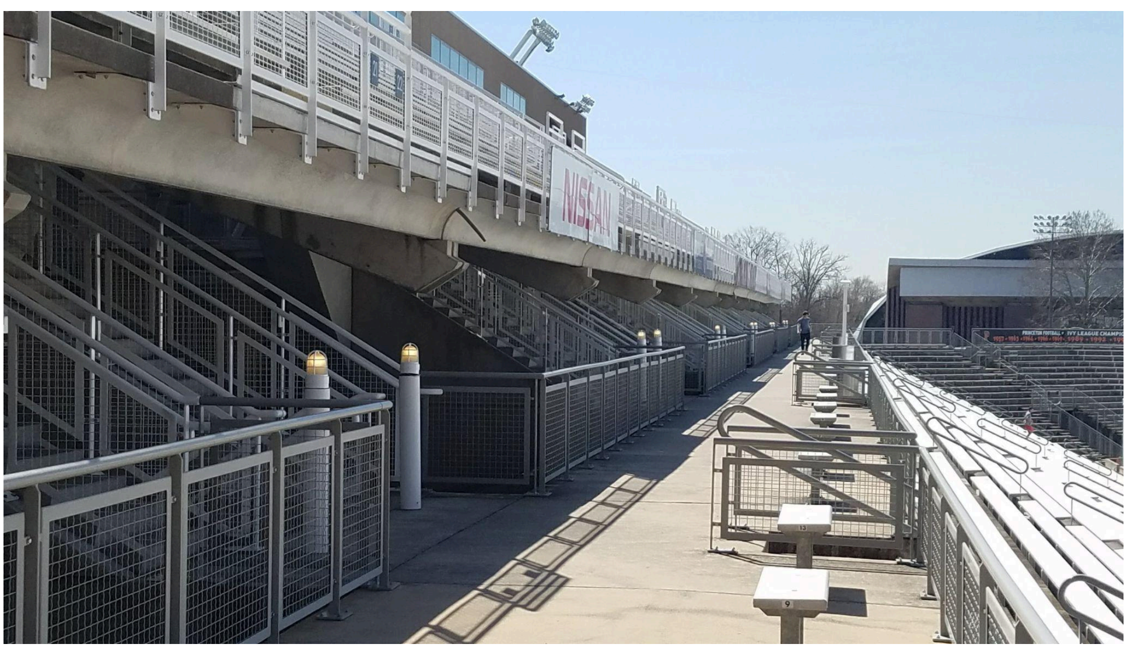
Light pollution affecting this area comes from i) Princeton Station, ii) Forbes College backyard lights, and iii) Graduate College Parking lot. Since the golf course is one of the few remaining dark sky areas, and also part of the fragile ecosystem areas, lighting should be minimized. College Rd. leading up to the Graduate College has Penn Globes with moderately good shielding, and decent light levels. The parking lot in the back is lit by sodium "shoebox" fixtures, and other than the shielding, the light level is only marginally above the desired one.

The Graduate School parking lot. Illumination levels are slightly above specs, but light spills out due to non-perfect shielding.

5. Locations with Significant Light Pollution and Glare

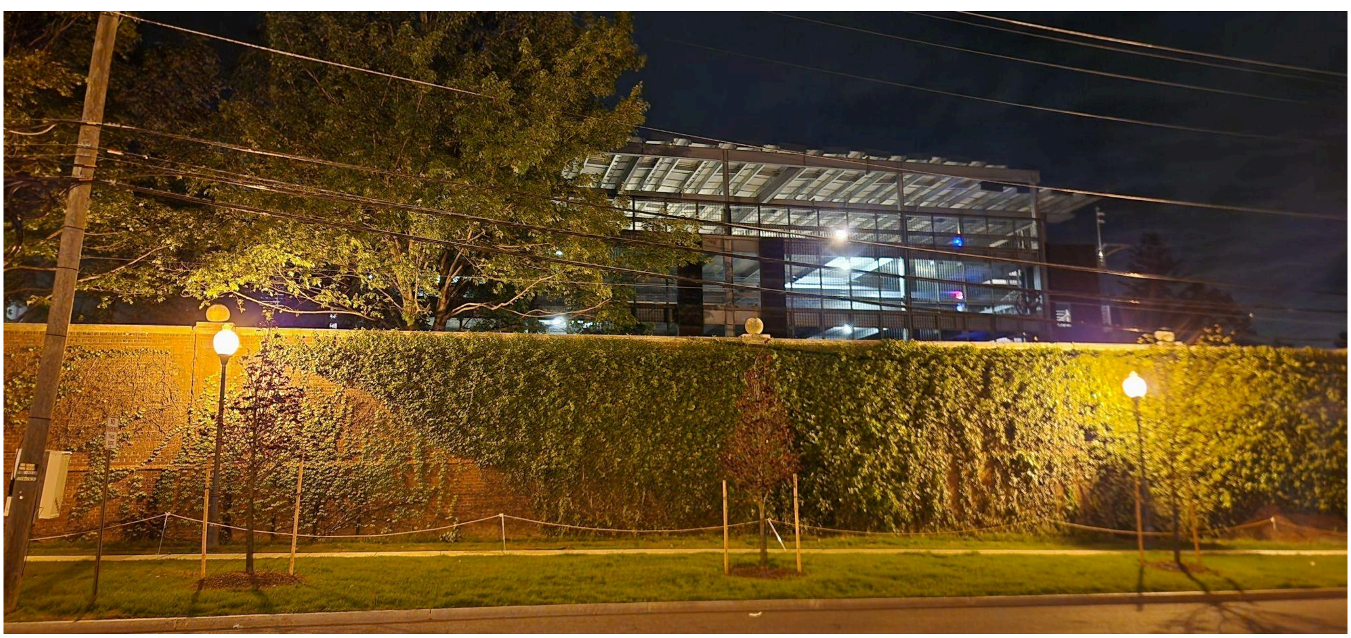
This section summarizes glare and light trespass. Both are detrimental to safety, and also violate the five principles of responsible lighting. There are many unshielded light fixtures on campus. There are area lights with > 50% light trespass or uplight.

Locations with significant glare are marked with the "fireworks" symbols. This is by no means an extensive map, but it identifies a few significant occurrences.



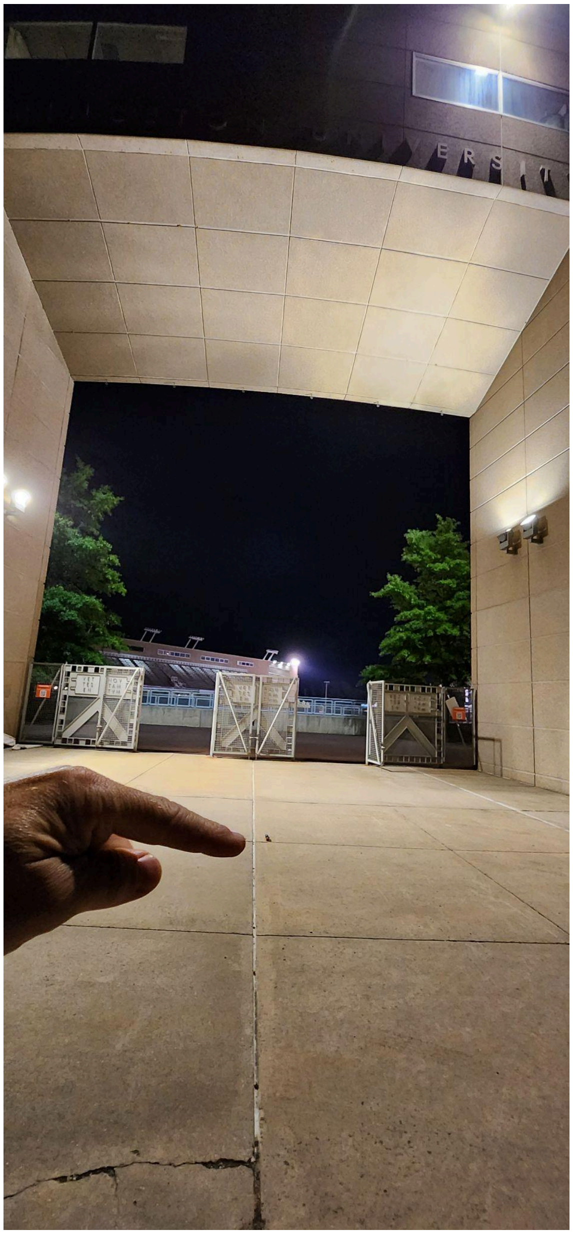
Unshielded bollards in the Stadium, often (or always?) turned on, including in the daytime. The cause glare at night, and are detrimental to safety.

Lights from the Unow nursery school spill onto Broadmead at night. Photo taken at midnight. The lights are so bright that they blind the pedestrians.



Prospect Avenue municipal spheres. About 60% of the light is emitted above the horizon (due to the supporting plate at the bottom of the light sphere). The lights cause glare, and the blinding brightness reduces safety in the area. Pedestrians walking over to other areas are not dark adapted, and will find otherwise normally lit places to be too dark.

The interior lighting of the geoexchange building is bright, wasteful, and a good fraction goes directly into the sky due to the poor design that did not account for light pollution. Compare the lighting level emanating from the building with that of the Penn globes in the background, or the Faculty drive illumination in the middle/top.



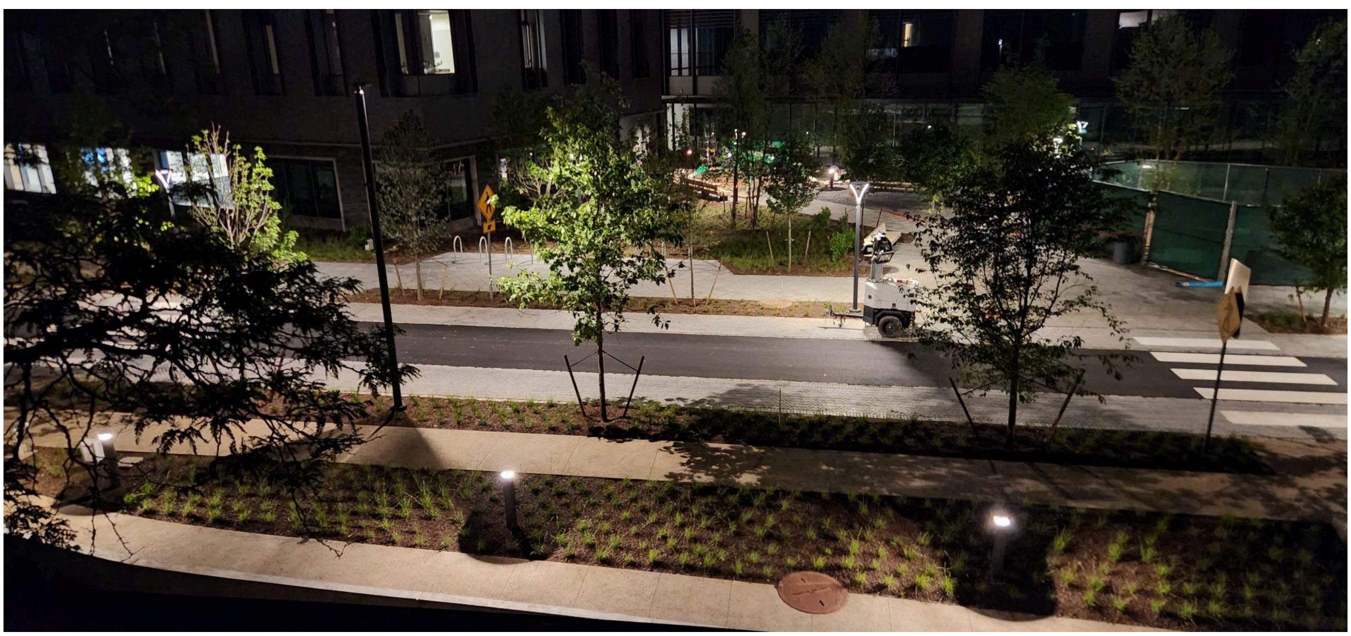
Overall illuminance under the archway lights is 5.9 FC, whereas the recommended values for this lighting zone are roughly at 0.2 – 0.3 FC. The glare from the overlighting is a safety concern, as other areas are clearly far less lit. Pedestrians walking through this area are losing their dark adaptation. This area is in front of Peyton Hall, which is a sensitive area for night time lighting.

Archway lights of the stadium. The upward-oriented lights are bright, and a fraction of the light misses the building, shining up in the sky.

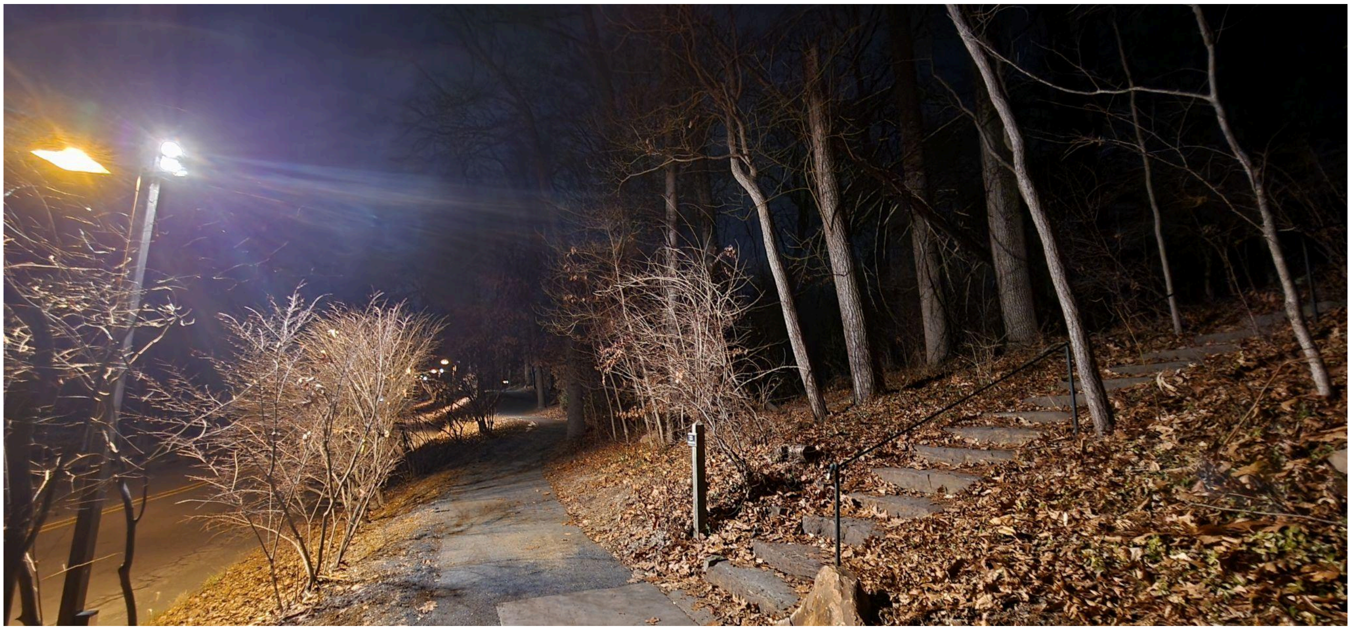
A good demonstration of how the upward-oriented archway lights miss the building. This is the usual side-effect of upward lighting.

There are only two places along the rim of the stadium with bright, unshielded area lights. One of these places faces Peyton Hall, and has at least 3 very bright floodlights. (Unused) office space in the top of the stadium has the lights permanently on.

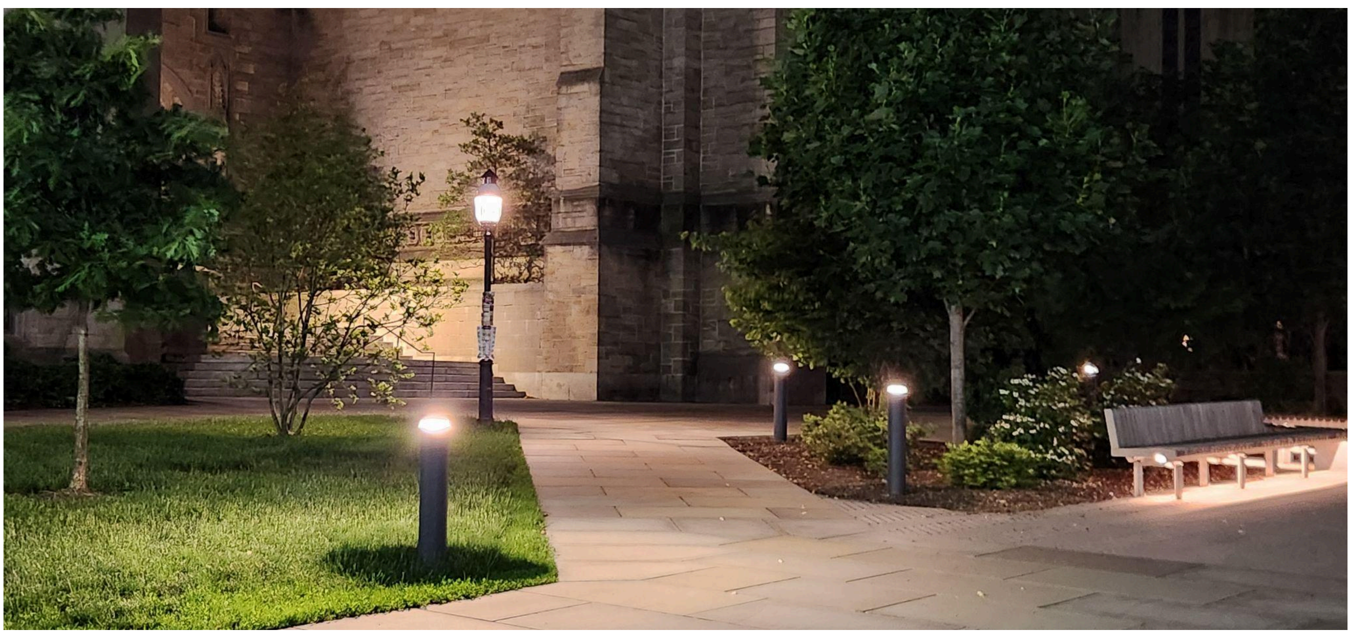
Unshielded area light next to Peyton Hall on the Lewis Library building. The light of this fixture directly shines in the Peyton telescope dome when the dome slit is open. It is also excessively bright, causing glare for pedestrians.



View toward the North from Peyton Hall's roof. The area in front of the ES+SEAS building is overlit, causing an overall glare. In addition, bollards are unshielded, causing direct glare for pedestrians. They are decreasing the overall safety of the area, and are wasteful.



New "area lights" illuminating the stairs at the corner of Faculty and Washington, with light spill in the woods. The lights are tilted in a ~30deg angle with much light going horizontally, and even up.



Unshielded, bright bollards at Princeton Chapel are causing glare.

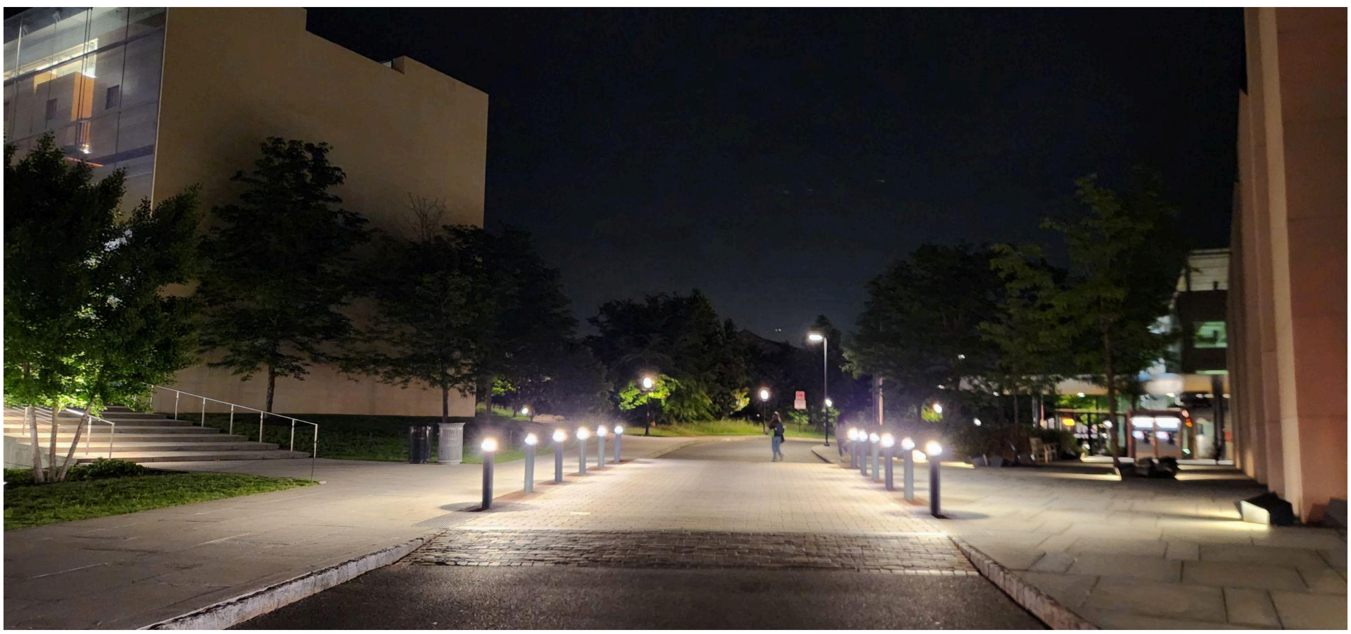
Unshielded, ultrabright greenhouse in the ES+SEAS building, causing glare and massive light pollution.

New, unshielded bollards cast light on the roof of Peyton and cause overall glare. Previously used bollards around Peyton BUG ratings with no uplight. Switching to these new ones is a step back.

With a little better facade lighting, which is dimmer and downward oriented, we could see a starry sky behind Nassau Hall.

Strong glare from area lights on the facility buildings on College Road. These lights cause glare for pedestrians walking on College Road. to/from the graduate college.

Almost vertically aligned blue LED area lights on College Rd.



Glare from many unshielded bollards at Princeton Station.

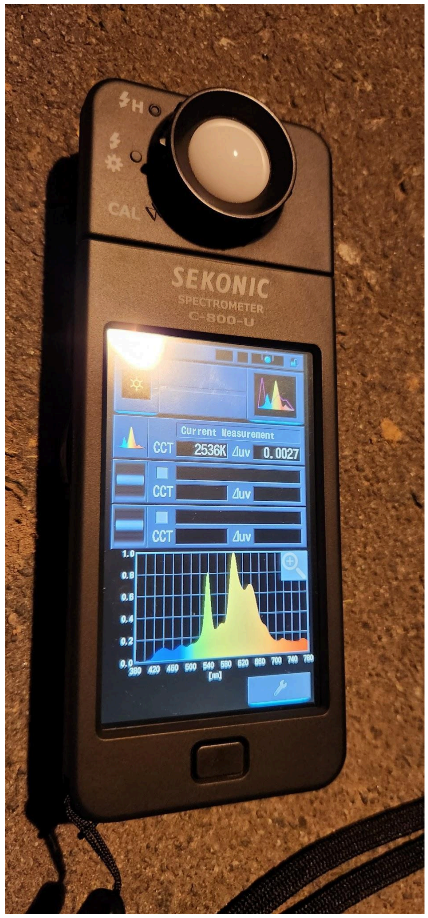
Color Temperature of Lighting

The spectrum of the outdoor lighting on campus was measured using a Sekonic C-800 spectrophotometer. There are very few areas left on campus with sodium lights, corresponding to ~2000K. These are some of the best lit areas, in the sense of proper shielding and no overlighting. One such area is the parking lot of the graduate college. The other one is Faculty drive.

The Penn Globe spectrum varies, with most fixtures peaking at 2500K, which is soft white. Some fixtures were fitted with a bluer/whiter bulb, giving a more industrial appearance.

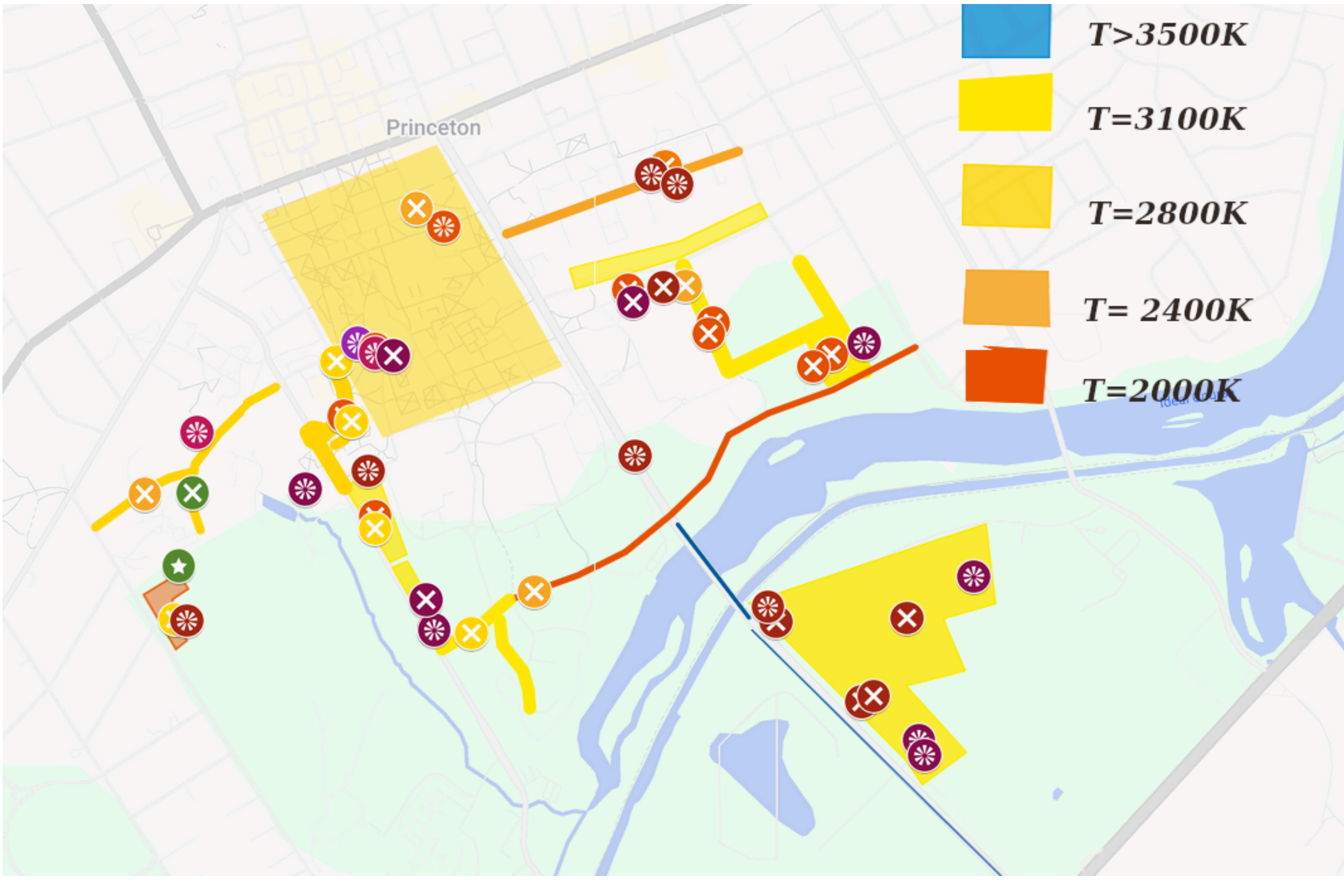
The new Bega 84* and 99* fixtures all shine at 3100K with a significant second emission at far blue (400nm). This blue emission is especially harmful, because it suppresses the evening production of melatonin.

Sodium shoebox lighting, peaking at equivalent temp of ~2000K, no blue emission.



Penn Glove emission, double peak, altogether equivalent to 2500K.

Bega 84* and Bega 99* emission: broad spectrum peaking at an equivalent temperature of 3100K, strong blue peak hiding in the red end.



Color-coded lighting map of Princeton. The color indicates the peak of emission. The line width or transparency of the shaded areas indicates the level of overlighting. For example, Faculty drive (center, almost horizontal) is orange, corresponding to sodium lights. The line is thin, the road is barely overlit. The Lake Campus is at 3100K and overlit (bottom right, deltoid area).

Good Lighting on Campus

There are some good examples of proper lighting on Princeton's campus.

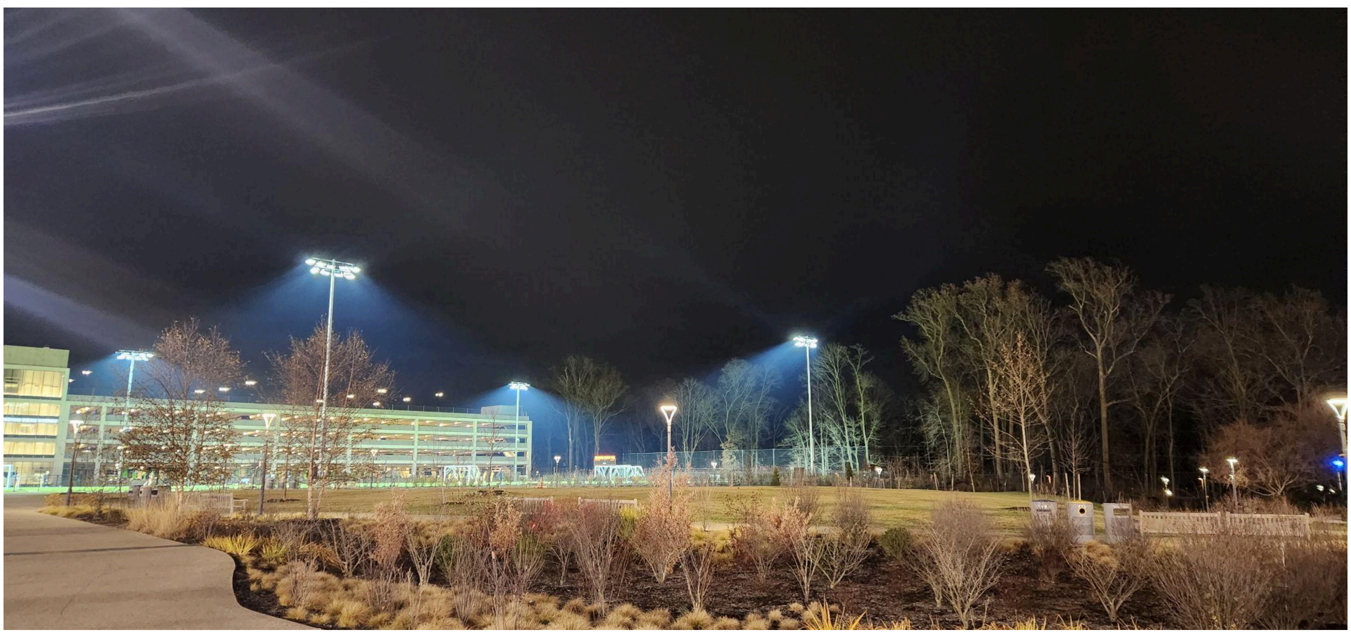
Fully shielded bollards on Prospect Avenue. This might be private property, or property rented from the University.

Richardson Auditorium at night. Thanks to NOT lighting the facade of buildings, we can see the stars and constellations as a beautiful backdrop to some of Princeton's architecture. In this image, we can see Orion behind Richardson. The building is "passively" lit by the stray light in the area.

Old-style bollards on the S side of Peyton. These have no uplight, in contrast with the new bollards on the N side of Peyton Hall.

Princeton's campus with Orion in the back. The only reason we can still take photos like that is thanks to no facade lighting of the building (they are naturally lit by the strong reflected stray light from the general lighting).

Some of the new sports fields have excellent, well-targeted lighting. This is untrue for the main stadium.



Another example of a well-lit sports field with excellent directional lighting.

Faculty drive with sodium shoeboxes.

Existing Conditions in a Broader Context

I have been monitoring Princeton's lighting and the light pollution in the area since 2011. I have been interviewing senior and emeritus faculty who have been living in Princeton since 1960. The Milky Way was an easy sight from Poe Field in the 1980s (Prof. LaMarche), and it was routinely visible from the Riverside area in the 1990s (Profs. Paczynski, Gunn). I occasionally caught a glimpse of the summer Milky Way from the Lakeside around 2011/2012. Stars, constellations, and the brightest stellar clusters were routinely observed with the naked eye from Fitzrandolph, the current location of the Stadium Drive. Strolling through the campus at night in between 2014–2019 was a unique experience, remarked by many visitors, with a view of the Big Dipper behind Princeton's Chapel, the North Star above Nassau Hall, or Orion behind Richardson. It was noted by many of our esteemed visitors and our student body that we are unique amongst Ivy League campuses by offering this connection with the sky (try that from Harvard/Boston!).

Between 2016 and 2025, the sky brightness above Princeton has increased by a factor of three[4]. More than 90% of this increase is due to the development of lighting on our campus. This wiped out many of these delicate and unique experiences. It paralyzes teaching astronomy, and it sets a poor example for our ~2000 students graduating each year, carrying their knowledge elsewhere. Sustainability and eco-friendliness are strong principles our University adheres to. Lighting up our fields, woods, fragile ecosystems, and the night sky is in stark contrast with these principles.

[4] Based on sky background measurements, drone imagery, and limiting magnitude measurements. An important reference work is Nicholas Barton's senior thesis on light pollution (2015).

While astronomy may be a niche, experiencing our place in the Universe and the connection between mankind and constellations remain very important for Princetonians. While hundreds of testimonials have been collected to this effect, let me quote two of my favorites:

"*I am on the campus often, attending classes, lectures, concerts, or simply taking a walk. Without meaning to sound like such an old fogy, I have to say that all the lights everywhere make the campus so much less inviting and romantic than it used to be. (The girl who became my wife and I met on a nice, dark evening on Prospect Ave some 55 years ago. We are still together. Today, with all the bright lights, she would have taken one good look at me and decided to walk the other way. Please, dim the lights.)*" – Alexander Geiger, Class of 1972

"*Pollution sullies natural beauty. Light pollution is no exception to this rule. Needless light at night prevents us from gazing at the natural beauty of the cosmos. I remember even ten years ago having some difficulty getting away from the lights of campus. And returning to Princeton since, I've noticed more needless light at night---parking garages floodlit near once-barren spaces we used to go to observe other worlds. Now those worlds are shut off from view, veiled from our eyes of our own doing. This saddens me. I worry that current and future Princeton students won't be able to have the wonderful experiences that I had*." – Thomas Zach Horton, Class of 2015.

Hundreds of others can be found at https://starryprinceton.org/testimonials.

The new lighting in the Lake Campus area, Stadium Drive Garage, the ES+SEAS building, the Dinky Station, and elsewhere on campus transformed the subtle, unique, park-like ambiance to that of an industrial parking lot. Lighting levels were measured at all these places, and are consistently factors of many times higher than the recommended IES values; at some places by a factor of 10! A pleasant evening walk is spoiled by the blinding brightness, and instead of a vibrant outdoor social scene, we see overlit, barren scenes of empty streets crossing through the Lake Campus or at the Stadium Garage. This is especially noticed by international students; indeed, the average light emitted per capita in the USA is 5x higher than in Germany, Switzerland, or Denmark.

Who would like to take an evening stroll here? Walkway in the middle of the Lake Campus field.

These lighting levels do not increase security, but the overlighting and the direct glare are detrimental to security. Even the general feeling of (false) security is violated by these levels of light and the associated glare. Finally, our mission at Princeton is to educate. We might as well educate our esteemed crowd of students on the norms of delicate lighting, dark adaptation, eco-friendliness, and real safety.

Conclusions on Existing Conditions

Princeton's lighting is inhomogeneous in terms of illuminance, glare, spectrum, and homogeneity.

Penn Globes – The aesthetically pleasing "classy" Penn globes provide a moderate level of lighting, broadly compatible with the desire of a "park-themed aesthetic" of the campus. There is a variation between penn globes; some are better shielded, some produce more glare, depending on the vertical positioning of the bulb. There is also variation in terms of the top cover; some have translucent top covers, leading to huge uplight (McCosh walk). With the 60 ft spacing, they have dark areas in between the poles, which was noted in the 2015 master plan: "*To preserve the park-like nighttime aesthetics of the campus, sparsely locate pole lights along walkways. This applies to walkways that are adjacent to and distant from roadways. Note that very low light levels between poles are to be expected*". This feature is good for those looking for a "romantic" stroll while enjoying the park-like ambiance, even looking up at the sky when they are in between poles. This feature is bad for those looking for a city-center feeling with homogeneous illumination.

Faculty Drive Shoebox Sodium – Perhaps one of the best lighting schemes on campus is that of Faculty Drive. One short section on the West side has shielded and relatively dim LED roadway lights, while the longer section all the way to Broadmead has shoebox sodium lights with only slight overlighting.

Bega 84121 – The new BEGA 84121 fixtures have slightly better BUG rating of B1-U1-G1 than the penn globes, and provide a more uniform lighting, but they are seriously overlighting the targeted areas (by factors of many). All of them are fitted with ports for intelligent controls (dimming, timers), but such controls were not installed.

Bega 99156 – Similarly, the BEGA 99156 fixtures for roadway lighting have an acceptable BUG rating, but just like the BEGA 84121, they are too bright. Many of these roadway lights appear redundant; for example, the Bega 84* walkway lights on both sides of Ivy Lane, and the light spilling from these fixtures onto the roadway, provide illumination of the roadway that is in excess of the recommended values. This was tested at Stadium Drive, where the roadway lights were not yet turned on, only the sidewalk fixtures contributed to the illumination of the road. Recent development on campus lit up areas that were formerly not illuminated; this includes many of the internal roadways, such as Ivy Lane, Stadium Drive, and the Lake Campus area. As discussed earlier, these roadways received passive low-level lighting from the adjacent walkways, and are not meant for pedestrian traffic, given all of them have sidewalks, sometimes on both sides (Ivy Lane). Some of these areas intersect fragile ecosystems (Lake Campus) or sensitive areas (Peyton Hall).

Area lights — The campus has been patched with makeshift/on-demand solutions of area lights. Cumulatively, there are hundreds, if not thousands of these, with new ones popping up all the time. They use LED technology, and some are extremely bright, causing unnecessary glare and light trespass. Examples are the backyard lights of Forbes, transforming the starry picnic area of Forbes into a bright patch with light spilling out on the golf course, or the area lights on facility buildings on College Rd. Another example is the slant roadway lighting on Washington Road, aimed at the woods. The rate of such lights showing up far exceeds the rate of these lights being adjusted or eliminated upon recognizing their suboptimal design or installation.

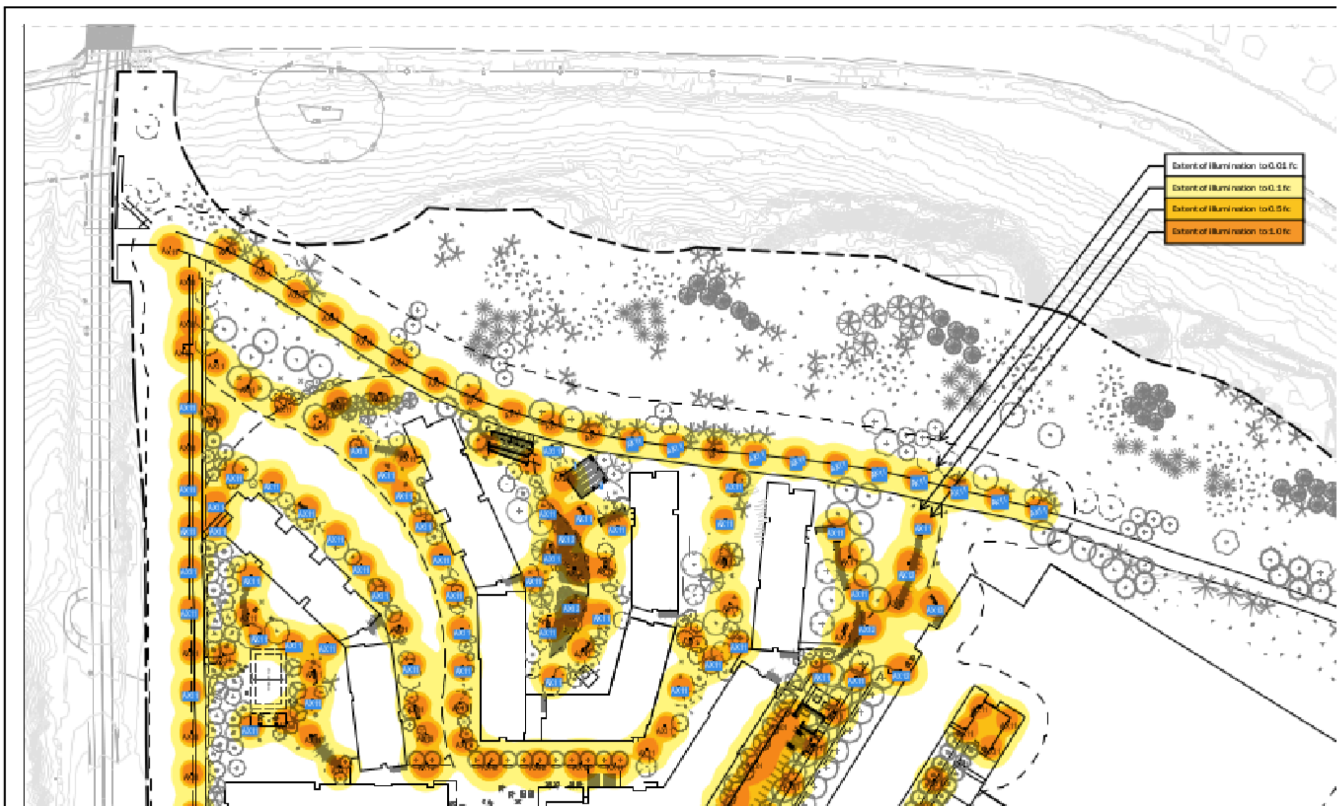
Building lights – There has been a growing number of buildings with strong light spilling out from inside: ES+SEAS building with its greenhouse and offices, the thermal exchange facilities at Stadium Drive and at the Lake Campus, and the Unow Nursery.

Bollards – The new bollards on campus have terrible BUG ratings and are causing an unwanted glare. If anything, they make the areas less safe due to blinding pedestrians. Old style bollards on the South side of Peyton are much better.

Color temperature – Very few lights on campus are sodium, with an equivalent color temperature of approximately 2000 K. The Penn Globes scatter around 2500 to 3000 K. The new Bega 84* and 99* lights, unfortunately, are at 3100K with a secondary peak in the far blue. It is an unfortunate trend that lights have been trending in the blue (=hot color temperature) direction. There are no amber LEDs on campus, yet they would be in between sodium and the Penn Globes, with a warm glow and friendly ambiance.

Light pollution, ecosystems – Current lighting does not take into account sensitive areas, fragile ecosystems, and the desired night-time environment thereof. No amber LEDs are used on campus (in sensitive areas), and dimming and motion-sensing technologies are not yet employed. The thousands of new BEGA 84* and 99* fixtures are all capable of such dimming. Most fixtures on campus have BUG ratings greater than 0-0-0; Bega 84121 is B1-U1-G1, Bega 99156 is B1-U0-G1, and the Penn Globes are B2-U2-G1.

Departure from plans and previous master plan – Lighting levels as implemented are different (higher) than the original design. Consider the lighting design for the Lake Campus, as shown below, with the highest level of illuminance under the poles indicated as 1 FC, and the light trespass into the LZ0 Canal Park being less than 0.01 FC within about 10 meters.



Original lighting plan for the Lake Campus (excerpt)

In reality, the implemented values are 3.1 to 3.9 FC under the poles, i.e, about 3-4 times the planned. The light trespass to the nature area is significant (at least 10 times higher than the claimed 0.01 FC). Light spill from the buildings is not indicated in the original design, but is very significant.

Light trespass into the D&R Park at Lake Campus.

Light trespass from floodlit buildings.

Acknowledgements

I wish to thank Lee Brandt from HLB lighting design for her dedication to this enterprise, and for visiting Princeton's Campus for a night walk. I learned many things from her. I thank Anthony Keyes for helping with the measurements and maintaining the starryprinceton.org site, and my numerous students contributing to photography and night sky measurements. Thanks to those hundreds of former AST205 students who emailed about their nighttime experience at Princeton, and their connection with the sky[5]. Finally, thanks to

[5] www.starryprinceton.org/testimonials

Prof. Gunn @ Astro, renowned expert of photometry and spectroscopy[6], for our numerous consultations on accurate illuminance measurements, photopic curves, previous conditions, and such.

References

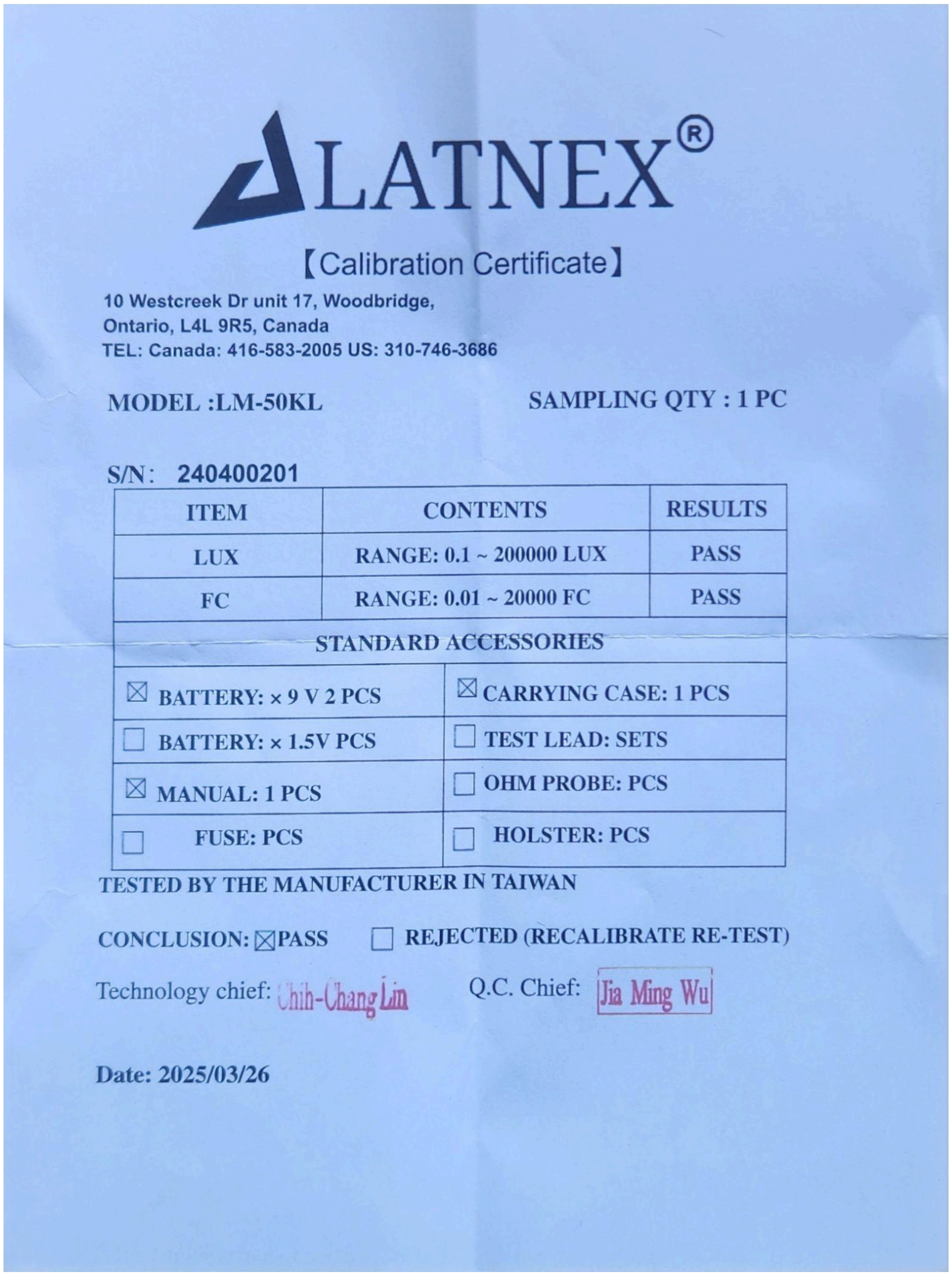
- Presentation by Gaspar Bakos on light pollution (PDF)
- Lake Campus Development and notes by Gaspar Bakos (PDF)
- Light pollution map centered on Princeton (LightTrends)
- Light pollution map centered on Princeton (Dark Sky Finder)
- Light pollution map info
- Princeton's 2015 master lighting plan (PDF)
- Princeton University crime statistics

General Light Pollution Resources

- International Dark Sky Association
- We're All Healthier Under a Starry Sky, Mario E. Motta, MD (PDF)
- Dark Sacred Night | A Light Pollution Documentary (YouTube)
- NJ outdoor lighting fixture bill S1610 | Zwicker, Mukherji (PDF)

[6] https://dof.princeton.edu/people/james-edward-gunn

Appendix



LATNEX®

【Calibration Certificate】

10 Westcreek Dr unit 17, Woodbridge,
Ontario, L4L 9R5, Canada
TEL: Canada: 416-583-2005 US: 310-746-3686

MODEL :LM-50KL SAMPLING QTY : 1 PC

S/N: 240400201

ITEM	CONTENTS	RESULTS
LUX	RANGE: 0.1 ~ 200000 LUX	PASS
FC	RANGE: 0.01 ~ 20000 FC	PASS

STANDARD ACCESSORIES	
☒ BATTERY: × 9 V 2 PCS	☒ CARRYING CASE: 1 PCS
☐ BATTERY: × 1.5V PCS	☐ TEST LEAD: SETS
☒ MANUAL: 1 PCS	☐ OHM PROBE: PCS
☐ FUSE: PCS	☐ HOLSTER: PCS

TESTED BY THE MANUFACTURER IN TAIWAN

CONCLUSION: ☒PASS ☐ REJECTED (RECALIBRATE RE-TEST)

Technology chief: Chih-Chang Lin Q.C. Chief: Jia Ming Wu

Date: 2025/03/26

Calibration certificate for the Latnex LM-50KL low-light illuminance meter.

Main Specifications of T-10A

Model	Illuminance Meter T-10A (Standard receptor head)	Illuminance Meter T-10MA (Mini receptor head)	Illuminance Meter T-10W$_S$A (Waterproof mini receptor head)	Illuminance Meter T-10W$_L$A (Waterproof mini receptor head)
Type	Multi-function digital illuminance meter with detachable receptor head (Multi-point measurements of 2 to 30 points is possible)			
Illuminance meter class	Conforms to requirements for Class AA of JIS C 1609-1: 2006 "Illuminance meters Part 1: General measuring instruments" Conforms to DIN 5032 Part 7 Class B		Conforms to requirements for special Illuminance meters of JIS C 1609-1: 2006 *1	
Receptor	Silicon photocell			
Relative spectral responsivity	Within 6% (f_1') of the CIE spectral luminous efficiency V (λ)			
Cosine correction characteristics (f_2)	Within 3%		Within 10%	
Measuring range	Auto range (5 manual ranges at the time of analog output)			
Measuring function	Illuminance (lx). illuminance difference (lx). illuminance ratio (%). integrated illuminance (lx·h). integration time (h). average illuminance (lx).			
Measuring range – Illuminance	0.01 to 299,900 lx; 0.001 to 29,990 fcd		1.00 to 299,900 lx; 0.1 to 29.990 fcd *2	
Measuring range – Integrated illuminance	0.01 to 999,900 x 10^3 lx·h 0.001 to 99,990 x 10^3 fcd·h / 0.001 to 9999 h			
User calibration function	CCF (Color Correction Factor) setting function: Measurement value x 0.500 to 2.000			
Linearity	±2% ±1 digit of displayed value			
Temperature/ humidity drift	Within ±3%			
Measurement speed	2 times/sec. (continuous measurement with 1 receptor head)			
Computer interface	USB			
Printer output	RS-232C			
Analog output	1 mV/digit, 3 V at maximum reading; Output impedance: 10 KΩ; 90% response time: 28 ms			
Display	3 or 4 Significant-digit LCD with backlight illumination (Automatic illumination)			
Power	2 AA-size batteries / AC adapter AC-A308 (optional; for 1 to 10 receptors) or AC adapter AC-A311 (optional; for 1 to 30 receptors)			
Battery performance	72 hours or longer (when alkaline batteries are used) in continuous measurement			
Operation temperature /humidity range	-10 to 40°C, relative humidity 85% or less (at 35°C) with no condensation		5 to 40°C, relative humidity of 85% or less (at 35°C) with no condensation	
Storage temperature / humidity range	-20 to 55°C, relative humidity 85% or less (at 35°C) with no condensation		0 to 55°C, relative humidity of 85% or less (at 35°C) with no condensation	
Size (W x H x D)	69 x 174 x 35 mm	Main body: 69 x 161.5 x 30 mm Receptor: Ø16.5 x 13.8 mm		
Cord length	–	1 m	5 m	10 m
Weight (without battery)	200 g (7.0 oz.)	205 g	260 g (Receptor head only: 120 g)	340 g (Receptor head only: 200 g)

*1 Conforms to requirements for Class AA of JIS C 1609-1: 2006 for all items except cosine response (f_2).
*2 Although measurements below 1.00 lx are possible, they may not be stable due to the effects of electrical noise.
<Notes regarding mini receptors and waterproof mini receptors>
*Do not touch the cable during measurements. Doing so may result in unstable measurement values.
*Secure the cable during measurements. Failure to do so may result in unstable measurement values.

Specifications of the Minolta T-10A high-sensitivity illuminance meter.