Diurnal Variations

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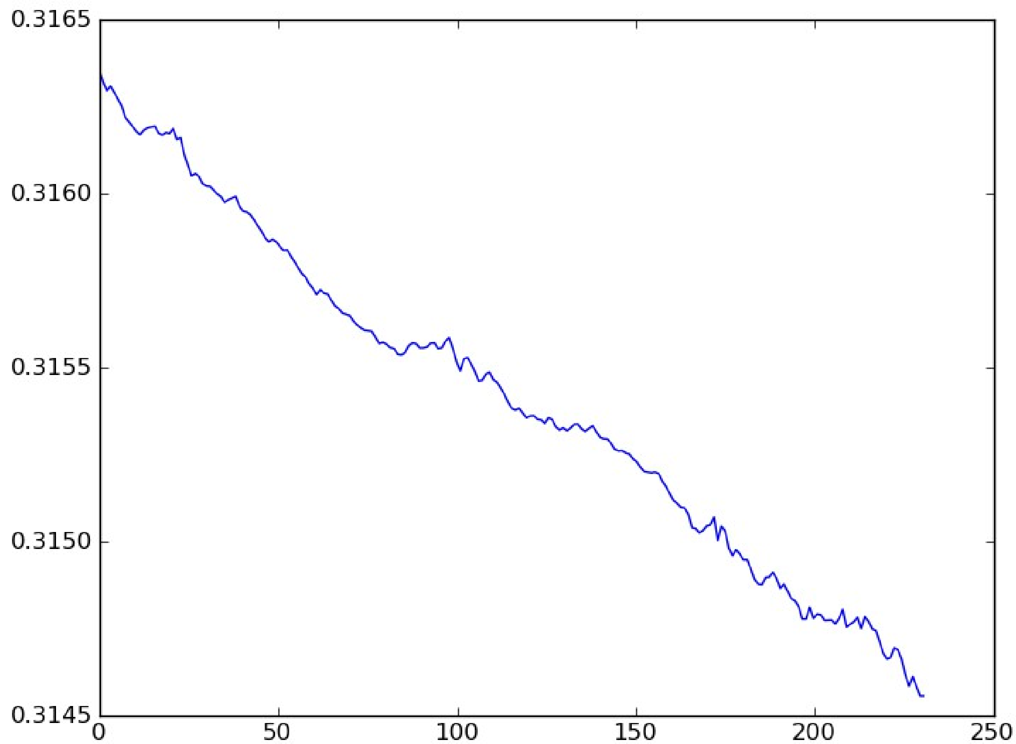
Note: unless otherwise specified, uncertainties are to be interpreted as a standard deviation per the GUM. Where I estimate the uncertainty in a measurement, I make a guess as to the total uncertainty as e.g. x ± y, then interpret y to be two to three standard deviations. I'll then present the uncertainty as y/2 or y/3. Of course, the number I thus give is non-statistical, but it is my best estimate using my 40 years of experience in making measurements.

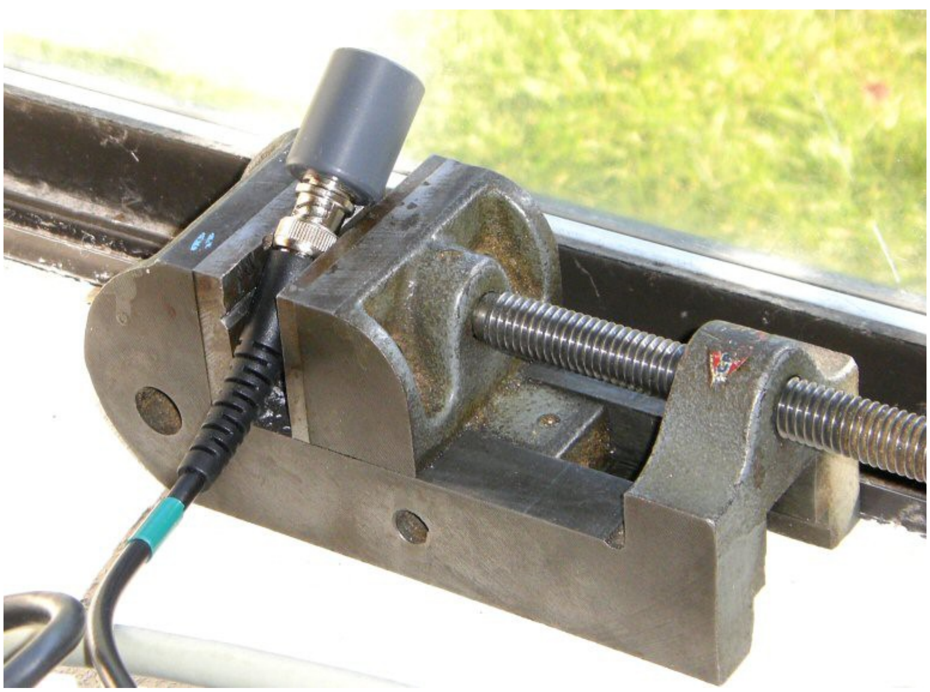
I have a cheap photodiode that I bought years ago from Radio Shack. I had mounted it in a chunk of PVC bar stock using hot melt glue and put a female BNC connector on it. One day, out of curiosity, I hooked it up to a voltmeter that my computer could talk to and I measured the voltage from the photodiode every second while it was pointed at the sky outside my window:



The horizontal axis is time in seconds and the vertical axis is the voltage across the diode. The thing that immediately struck me was the down and to-the-right slope. The only thing that came to mind that explained this slope was the rotation of the Earth. Of course, your eye can't detect a change in the sky's intensity in five minutes. The measurements were taken at about 5:30 pm in the Northwest US at about latitude 40 degrees. Sunset was about 3.5 hours later.

Here's a picture of the experimental setup:

The red arrow points to the photodiode in the PVC body. That's a chicken coop in the background; I'll refer to it again in relation to a later graph. Here's a closeup of the diode in its holder:



The longitudinal axis of the BNC connector, which is perpendicular to the face of the photodiode, is roughly 45° above the horizontal (i.e., this is the approximate elevation). The azimuth of the device is roughly 045° true. Thus, it is mostly looking at the clear sky in a northerly direction. This window does get sunlight coming in it from the east in the morning.

I then mounted the detector under the edge of the roof of my house and pointed it at about an elevation of 30 degrees at approximately true north. The detector probably picks up light from a solid angle of about half a sphere (2π steradians). Here's a plot of 2.8 days of data collection:

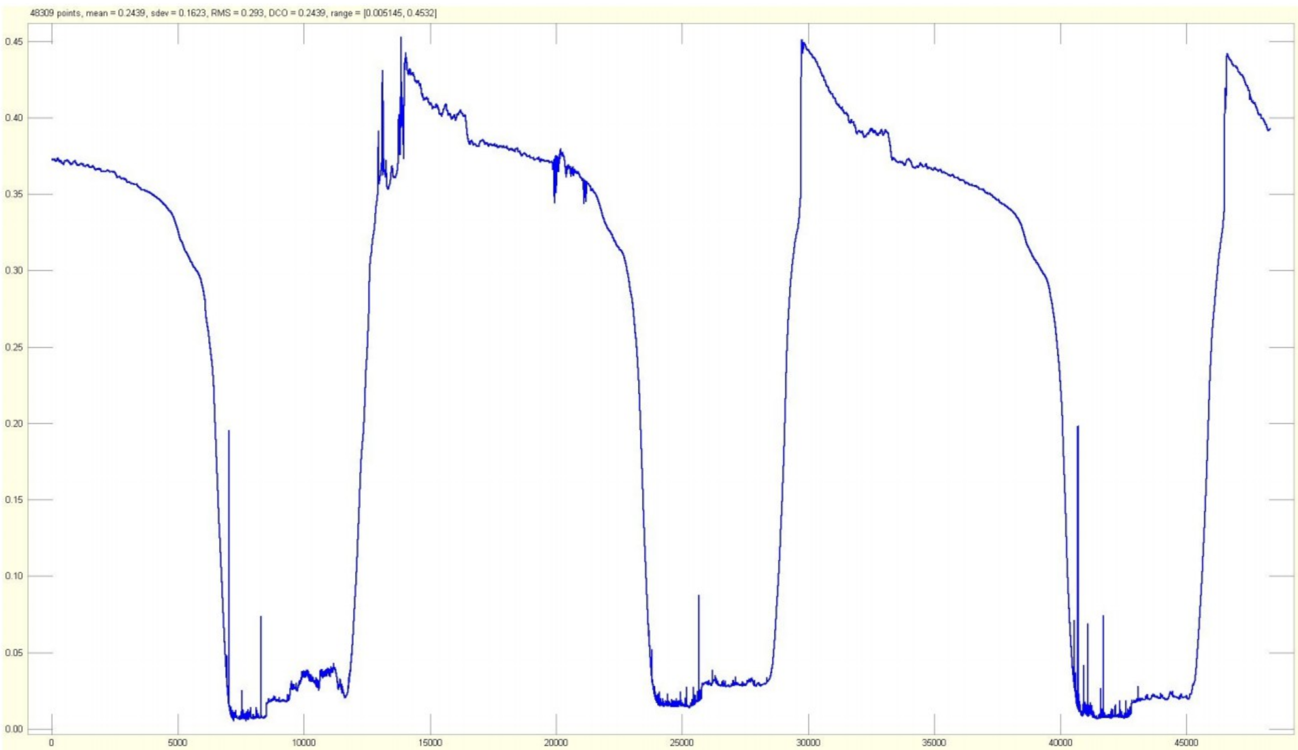


Figure 1

There are 48309 points plotted on this graph; point 0 was recorded at 21 Jul 2011 12:21:04 PM, Mountain Daylight time in the US. The sampling interval is 5 seconds. Each horizontal tick mark is 5000 points and each vertical tick mark is 0.05 volts. The fundamental frequency is $1/(24\ \text{hr})$ or 11.6 μHz.

There are all kinds of interesting features to interest the experimentalist in this graph. For example, the large spikes just after darkness on nights 1 and 3 are my wife turning on the outside lights when she goes out to the chicken coop to close the sliding door (if she doesn't, we can lose our chickens and ducks to raccoons and foxes). I closed the coop on the second night and did it a bit earlier, so I didn't need to turn on the lights. The smaller spikes might be airplanes coming in to land from the north; they typically turn on their landing lights around 100 miles out so the control tower can see them. The noise during the first morning around sunrise was probably due to some clouds to the east of where I live. I don't know what caused that noise around the points at around 20000 or 55000; it might have been a few clouds north of us. We've had essentially clear skies both during the day and night for the last week or so; it's more usual to have cumulus clouds and a few thunderstorms, so these data are probably as noise-free as they typically get. The small but noticeable step change roughly half-way through the night is curious -- it's not the moon, as moonrise is a bit after 6 am each day and the moon sets at around 8 pm. The other relative peaks during the first darkness are also curious.

I used the WaveXpress program from B&K Precision to plot these data and examine them in more detail. While it's intended to work with B&K's instruments, you don't need instruments connected to your computer to use the program, so it's a general-purpose plotting and manipulation program for graphs. You can download it for free and it runs on MS Windows computers.

Because electronic data-logging equipment can be had relatively inexpensively to connect to computers over the USB bus, this kind of experiment is something that could easily be done by school kids. In fact, I'd bet both the parents and the kids would have fun in setting up the experiment and collecting the data, then analyzing it and figuring out what's going on. It would definitely give the student a taste for what it's like to do experimentation. One would naturally want to know what causes the detailed variations in the graph and use the data to accept or reject various hypotheses about what's going on. About the only thing I can guarantee if you try this yourself is that you'll soon be doing more experiments yourself to satisfy your curiousity.

21 Jul 2011 Experiment

This section explains the graph in Figure 1 in more detail and shows the complete set of data taken.

The detector was mounted with a tie wrap to the soffit of the house just outside the western-most window of my computer room (so the BNC cable could go through the window screen):

Figure 2

The bearing was true north and the angle was about 30° above the horizontal. The data were collected for 7 days, one reading every 5 seconds.

Here's a plot of all the points taken:

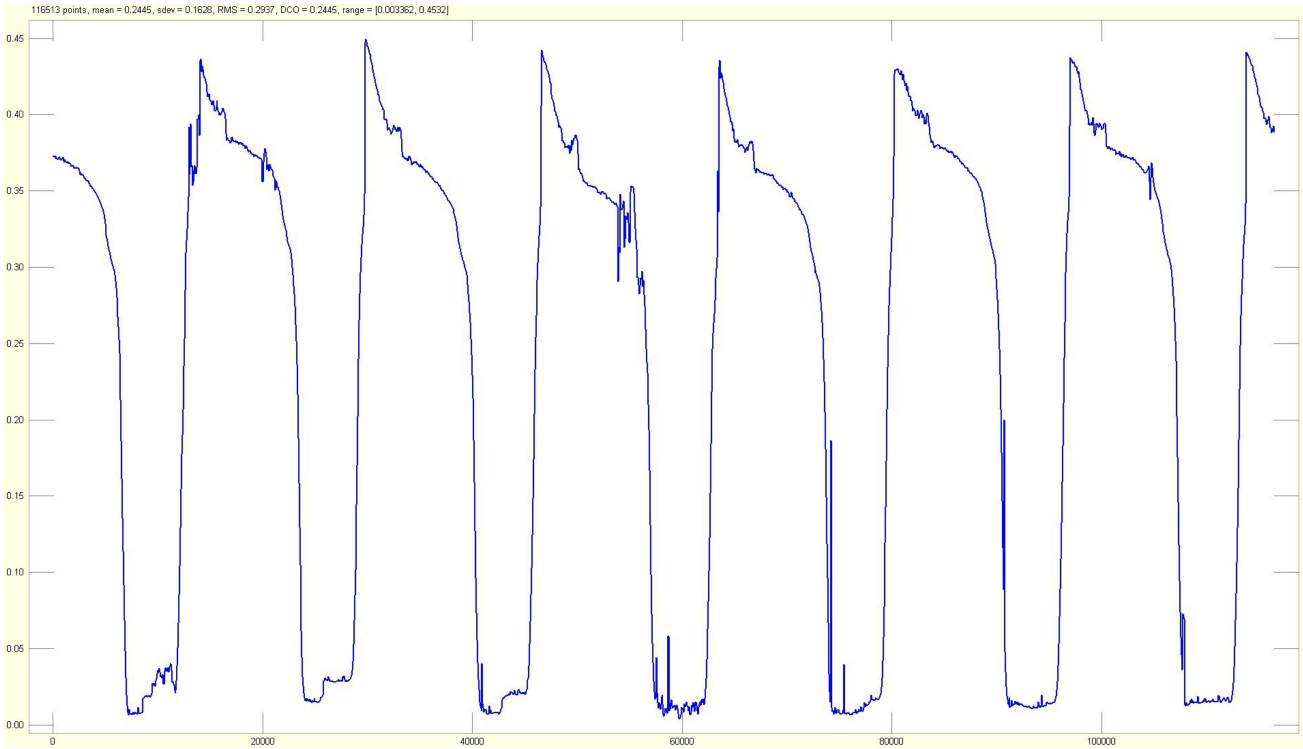


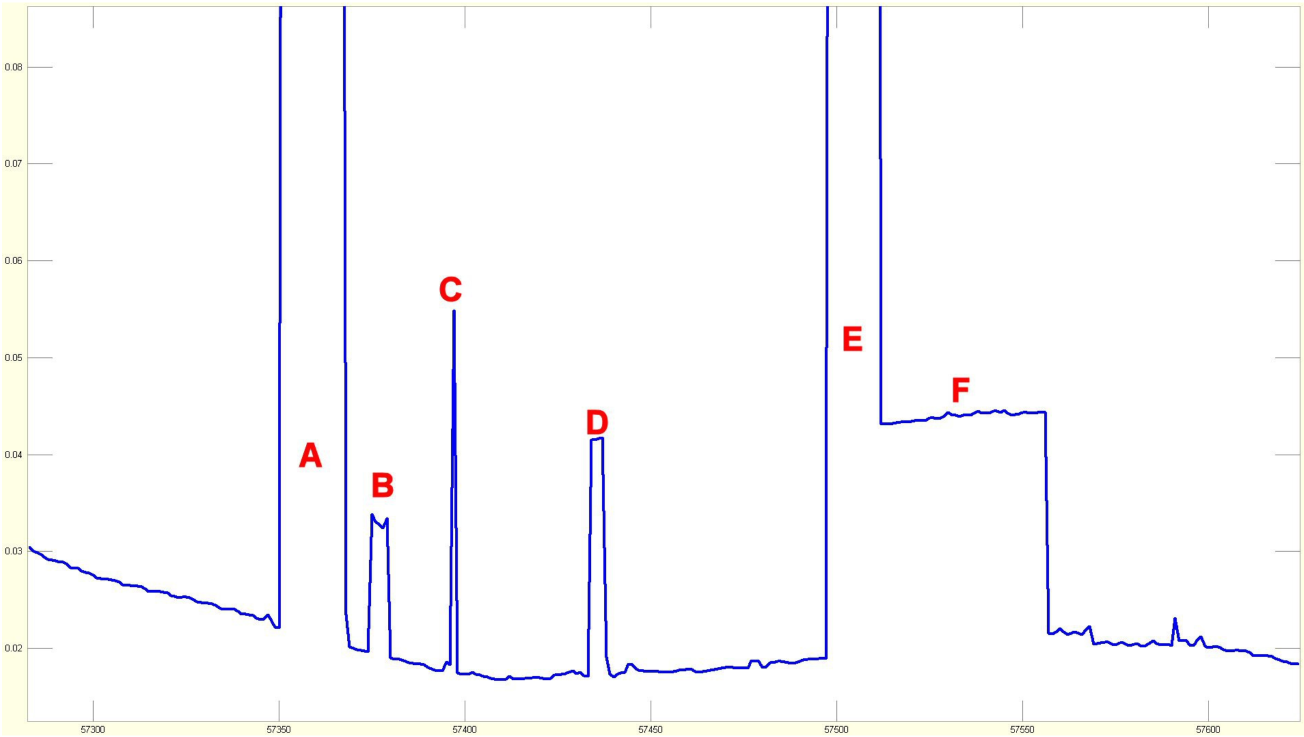
Figure 3

There are a total of 116513 points. Each horizontal tick mark is 20000 points or 27.78 hours. The lowest measured voltage was 3.36 mV and the highest measured voltage was 0.453 V.

There are numerous interesting details in this graph. The "noise" during the day was likely due to a few clouds in the sky. For example, the noise on the first morning had clouds around the mountains to the east.

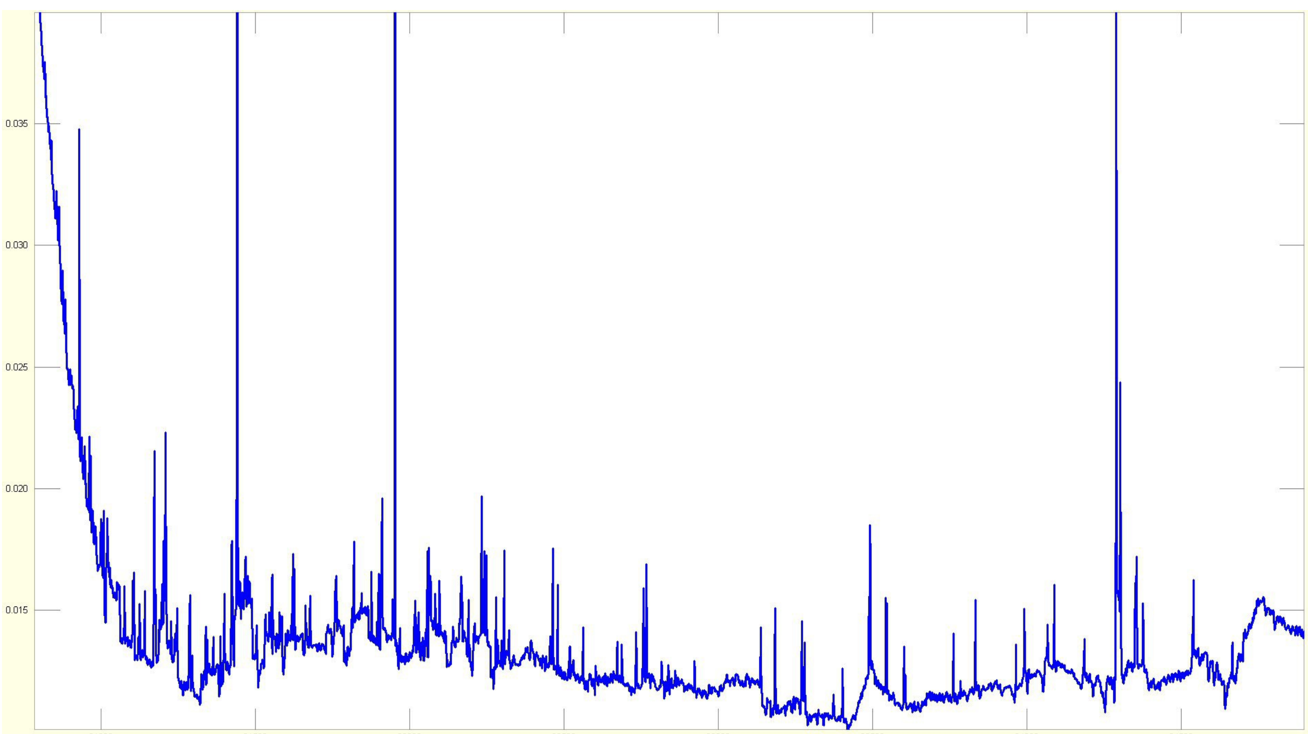
Every morning around 11 am the sun went behind the edge of the detector; this caused the dip seen at point 16500 and at corresponding points on later days. I verified this by climbing up on a ladder and examining the detector at 11:10 am on 28 Jul about 15 minutes after stopping the experiment.

Here are some details from the fourth evening:



Peak A is where my wife turned on our outside lights so she could close the door to the chicken coop. I'm not sure what points B and C are, but they are probably some room lights in our house. Point D is where I turned on the desk lamp next to my computer. Point E is where my wife went out the the chicken coop again, as our ducks had not gone into the coop at point A. Level F shows where I had left my desk lamp on for a while. The vertical distance from the lowest point on the graph to the height of peak D is 24.9 mV.

Here's (most of) the fifth night:



I would assume most of those smaller spikes are caused by airplanes flying into the field of view with their landing lights on. They could also be cars that drive by on the roads next to our house.

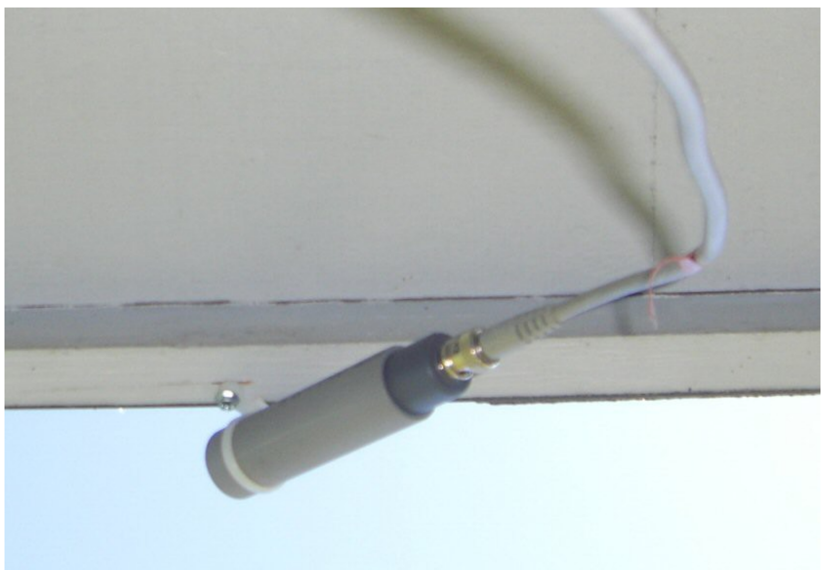
28 Jul 2011 Experiment

The purpose of this experiment was to greatly reduce the solid angle measured by the detector.

I mounted the detector in a tube of 3/4" schedule 80 pipe bored to be a tight fit to the detector's body. The end of the pipe to the end of the detector on the outside was 0.74" and the end of the tube to the end of the detector flush with the diode was 3.2" measured on the inside.

This was mounted to the roof's soffit outside my computer room in a similar fashion to the 21 Jul 2011 experiment and the sampling period was again 5 seconds. The elevation was measured with a Starrett protractor attachment to my machinists combination square and was measured at 32.5°. I estimate the measurement uncertainty as 2 degrees. The bearing again is true north; I estimate the compass measurement uncertainty as 2 degrees.

Here's a picture of the mounting with the camera looking straight up:



The tie-wrap clamps to the PVC tube, holding it to the soffit.

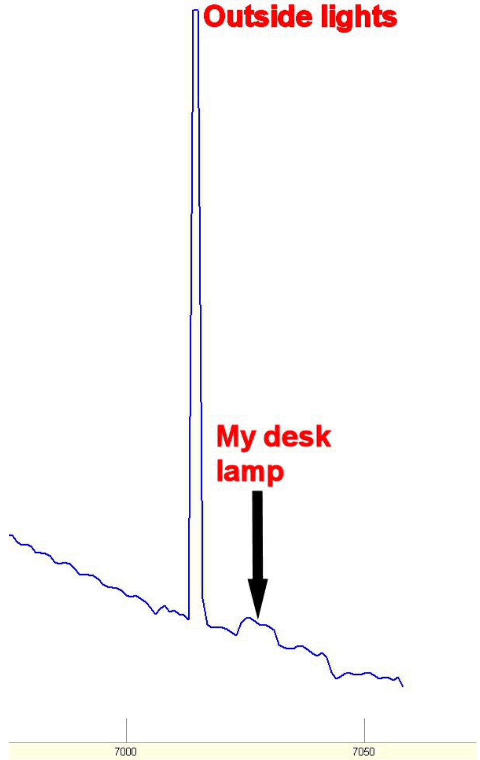
I started the experiment at 28 Jul 2011 11:58:49 AM.

The detector is 3.2 inches from a hole that's about 0.9 inches in diameter.   If a circle with radius r is at a distance h from a viewing point on a line normal to the plane of the circle through the circle's center, the solid angle subtended is

$$\Omega = 2\pi\left(1-\cos\left(\tan^{-1}\frac{r}{d}\right)\right)$$

Thus, we get the solid angle of the sky that the detector sees is 0.0612 steradians or 0.0049 of a sphere. The subtended angle is 8 degrees.

The preliminary data from the first afternoon and evening show that the signal contains quite a bit less noise than the "uncollimated" version. Here's a plot showing that the outside lights are still detectable (the light is probably being reflected from the leaves of an oak tree nearly due north of the detector):



My desk lamp is still barely detectable. The deck light was turned on for 10 seconds after the desk lamp, but I don't think it can be pulled out of the noise. From looking at the geometry when standing near the detector, this light is being detected either by reflection from the leaves of an oak tree about 20 m away, a larger neighbor's tree about 65 m away, or the flat white side of our trailer. The following shows the measured geometry:

Here's a picture that looks along the axis of the detector:

The two previous pictures demonstrate that the detector isn't looking at any surface directly (it's all a sky view). Thus, when our outside lights are detected, it has to be reflected light, probably from the trees or trailer (and, thus, this reflected light is bouncing off the walls of the collimating tube).

You can see there's lots of details to interest an experimenter -- and lots of hypotheses that need to be tested before you understand what's going on.