Current Status of the Vatican Observatory/IDA Night Sky Brightness Monitor (NSBM)
Food for Thought

Project description summary:

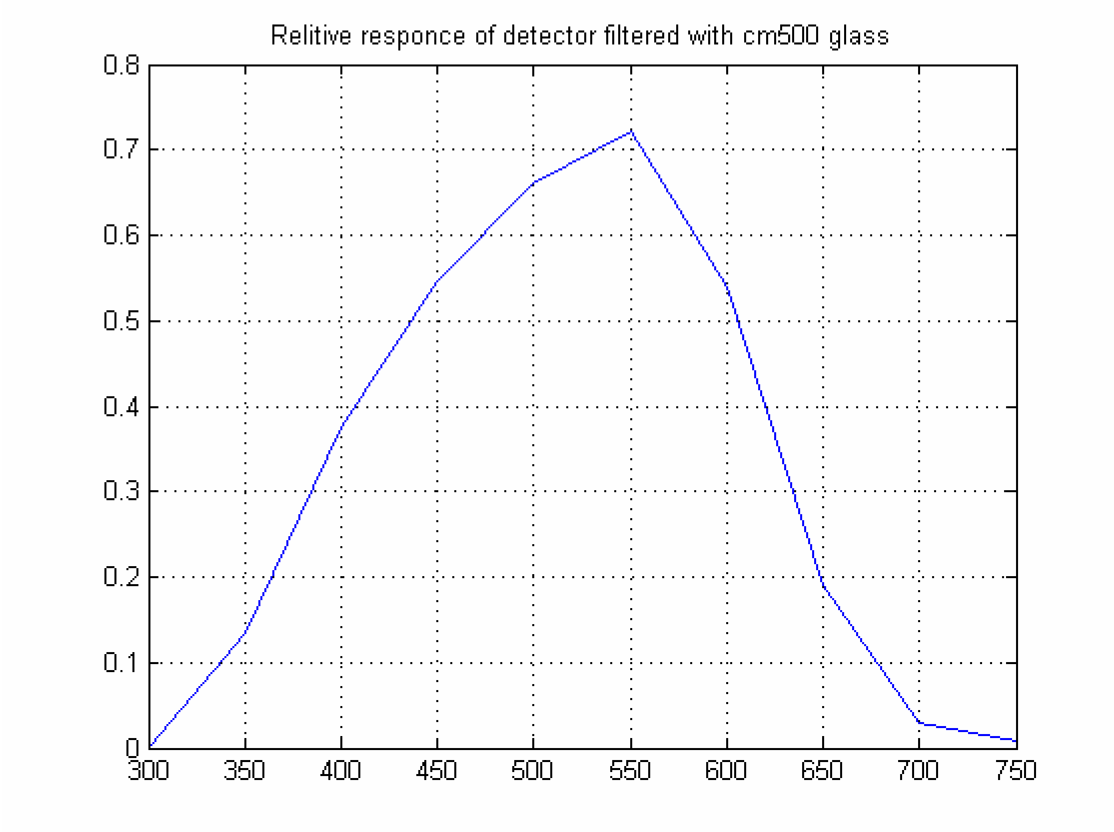
We have developed a technique for the measurement of the night sky brightness in the visual part of the electromagnetic spectrum. This device measures the sky brightness at two elevation angles as an attempt to separate the effects of variable atmospheric scattering from sky brightness variations.

Remote unit at Palomar site

The device consists of two units to be deployed at each measurement site, a remote photometer head and a base station that receives data from the remote head via a wireless spread-spectrum transceiver pair.

The remote head has two photometers that sample an area of the sky approximately 5.6 degrees in diameter at two elevation angles. The photo-detectors used to measure the sky brightness receive filtered light to define a spectral response centered in the visual range with a strong cutoff in the near infrared. The near infrared component part of the sky spectra is mostly due to geophysical phenomena in a dark sky.

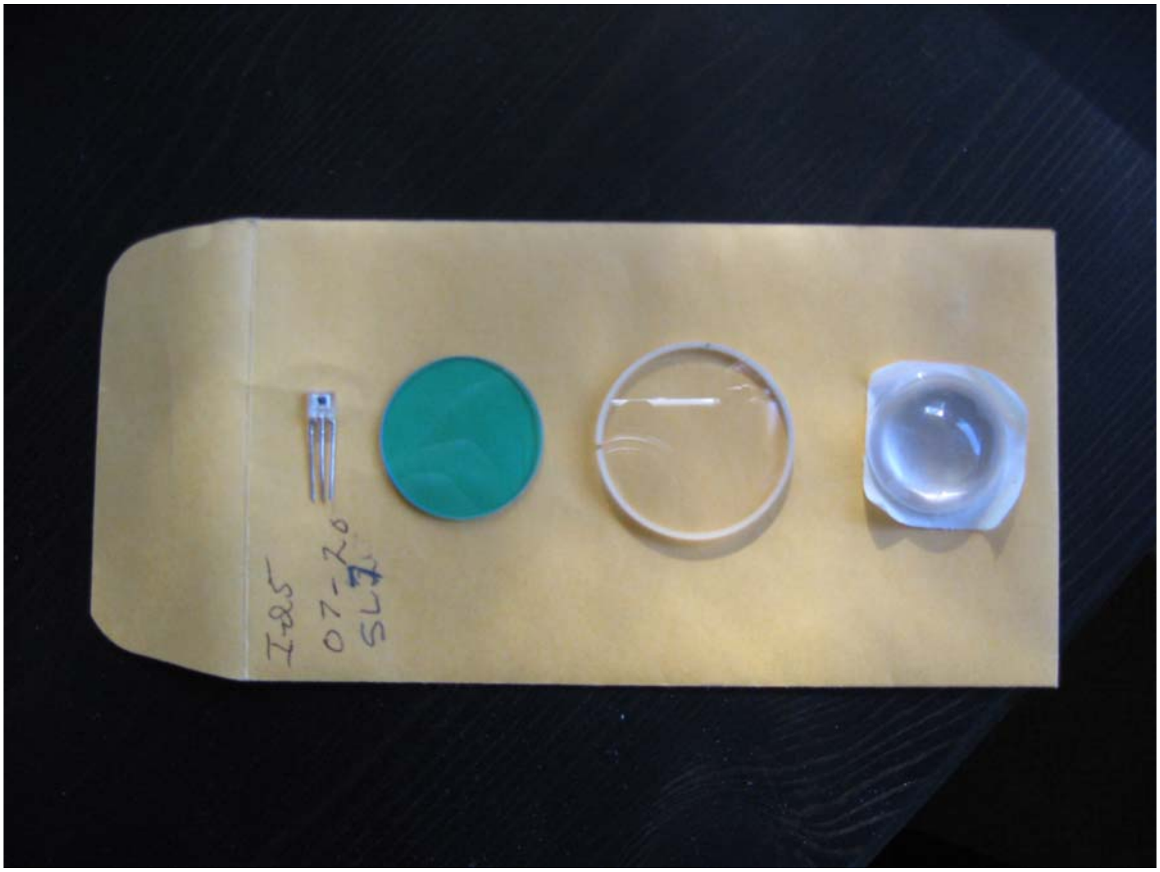
This spectral response is the result of a silicon detector filtered by Hoya CM500 glass and is the basis of our photometry system. It should be noted that the Unihedron SQM uses the same system and that the SQM development was inspired in part from our work.



Traditional Measurements are made using a V magnitude filter centered in the visual with a band-pass about one third of our photometers response. This broader response not only allows us greater sensitivity and thus resolution than a similar detector with a narrow band filter but includes wavelengths that are biologically active and those laser and led wavelengths used for outdoor display that would not be detected using a V band filter.

Our challenge is to understand what the systematic difference between standard systems and this new photometry used in the NSBM. Although absolute difference will occur between the NSBM and other system like used by the national Park Service long term rate of growth measurements will on its own prove to be of great value.

Due to the increasing interest on nocturnal studies, the SBM maybe of interest to the biological community and acceptance of this system could be rapid.



Optical components used in the photometer head.
From left to right: detector, filter, front window, and F 0.65 lens

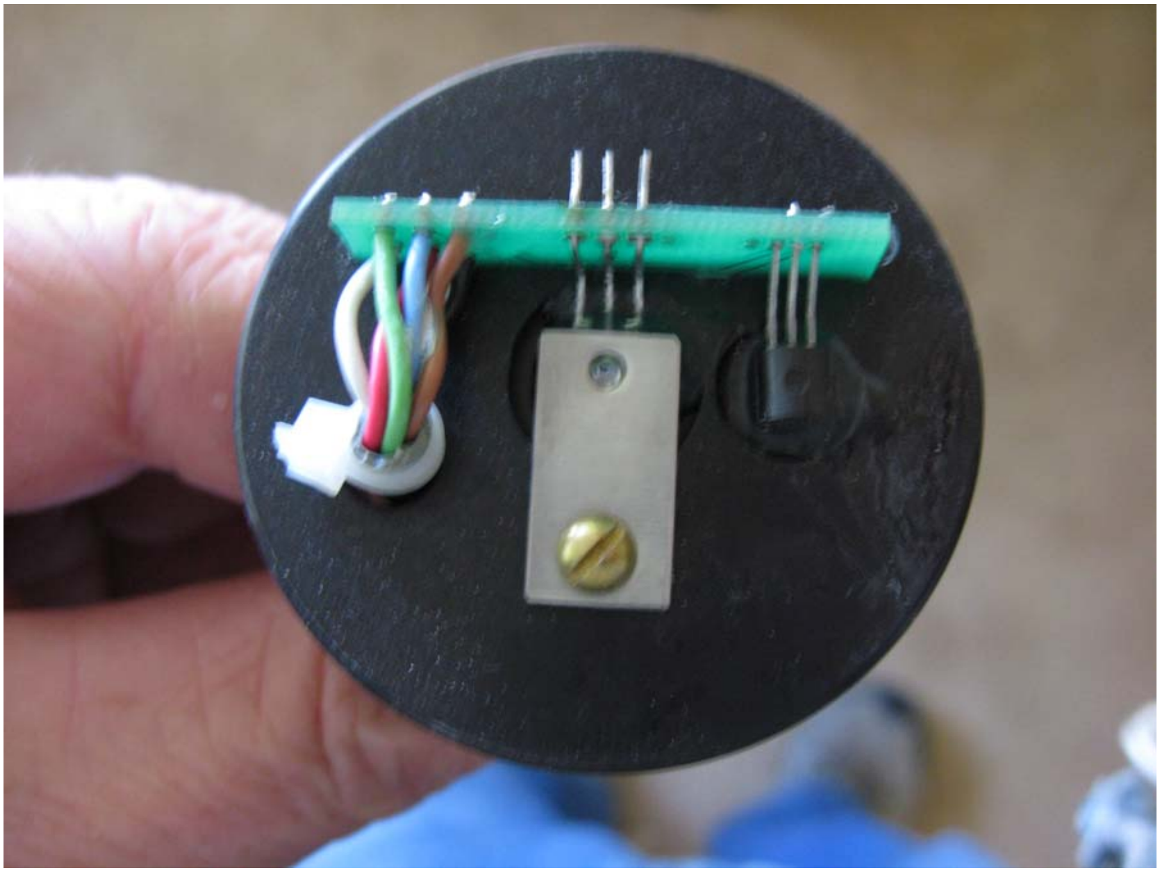
The optical components are assembled in the photometer barrel using adhesives. Due to the wide operating temperature range, care must be exercised to prevent contamination due to out gassing and separation leading to water incursion. We are continuing to explore what the final solution will be. The Hoya CM 500 filter is custom made for us and the glass window was bought in bulk surplus. The entire optical assembly is replaceable as the quality of the photometer head is based on the detector performance which requires the majority of the effort in photometer head construction.

We feel that with proper training, relatively unskilled persons could produce this assembly quickly. Quality control will need to be in place as finger prints or other forms of contamination could produce variable transmission depending on temperature and humidity.

Photometer body with three point mounting

The Photometer head barrel is machined out of solid aluminum by a numerically controlled milling machine. The three point mounting system allows for easy removal and replacement for cleaning the front window. A space between the outer baffle tube is necessary to drain water and provide a thermal stand off reducing the temperature extremes produced by solar loading and nocturnal radiation cooling.

The grove visible in the two o'clock position provides a vent path to equalize pressure and prevent trapped moisture.



Photometer Head electronics note temperature sensor to the right of the detector in center

As will be discussed later, an important aspect of this development has been the taming of the temperature effects. The detector is incased in a plastic package with three metallic leads for power ground and signal. The thermal conductivity of these leads produces a temperature gradient resulting in a time varying offset some time grater than a dark sky signal. The remedy is to pot the detector in the photometer body to produce as close as possible, an iso-thermal environment.

In addition to the detector a temperature sensor provides data to compensate for the dark frequency dependence. During the selection process the detectors are subjected to a temperature change and the dark frequency is recorded. Three values are computed from these data and they are:

Dark count rate at 20 C
Dark count rate slope
Zero count rate temperature.

The detectors display both positive and negative temperature coefficients. Some detectors will have a zero count rate in the temperature range considered operational and that is from -40 C to + 60C. We reject detectors that have a zero count rate in this temperature range.

.

Completed Photometer head

When a detector head is completed it receives a serial number. Associated with that serial number is the:

Dark count rate at 20 C
Dark count rate slope
Zero count rate temperature.
Photometric zero point.

The photometric zero point is the Magnitude that produces a count rate with the dark offset subtracted of 1 Hz.

Three point mounting with quick release inserted in baffle tube

A solar charged Battery powers the remote unit for ease of installation, protection from lightning, and will continue to store data in the event of a power black out which may provide an opportunity to observe the sky brightness during a blackout period.

To receive the remote head data and transmit it to a central location, a base unit connected to the internet processes the received raw data, compensates for the temperature effects, formats and sends not only the two elevation sky brightness measurements, but the device status including battery voltage, device current demand time, date and detector temperatures.

The data collection time tag is synchronized with web based time servers and should be better than one second.

This data is then transmitted via email to a specific location, typically hourly, consisting of sixty one minute measurements

Packaged Base Unit

The base unit connects to the network with a standard cat5 cable. The display at the bottom is multi-function. During the power up it displays the IP address and time that it calibrates the internal clock to using a network based time standard. This ensures global synchronization to better than a second.

During normal operation this display also indicates the unit number of the remote photometer, its two magnitudes and the signal strength received.

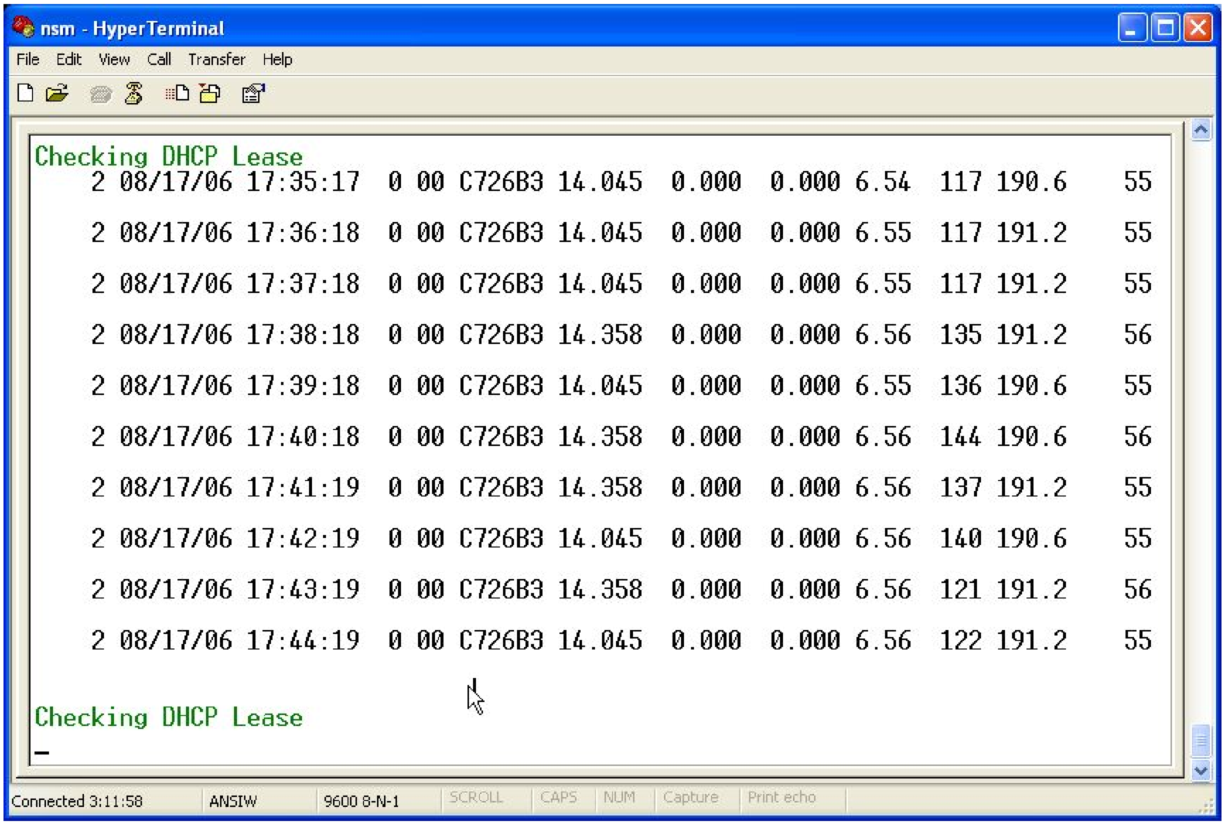
The previous version required the connection of a RS232 terminal for set up and this proved to be problematic for the general public.

Base electronics

The base electronics is powered from a wall plug supply producing 12 volts. In the upper center of the board is a removable memory card. Currently this card will hold about 25 years worth of data. The data is transmitted and keeps track of the last successful transmission. This way if data is not transmitted to the remote host, the system will retry until successful. The local control can also manually dump what ever data is requested in case the host computer needs to be refreshed.

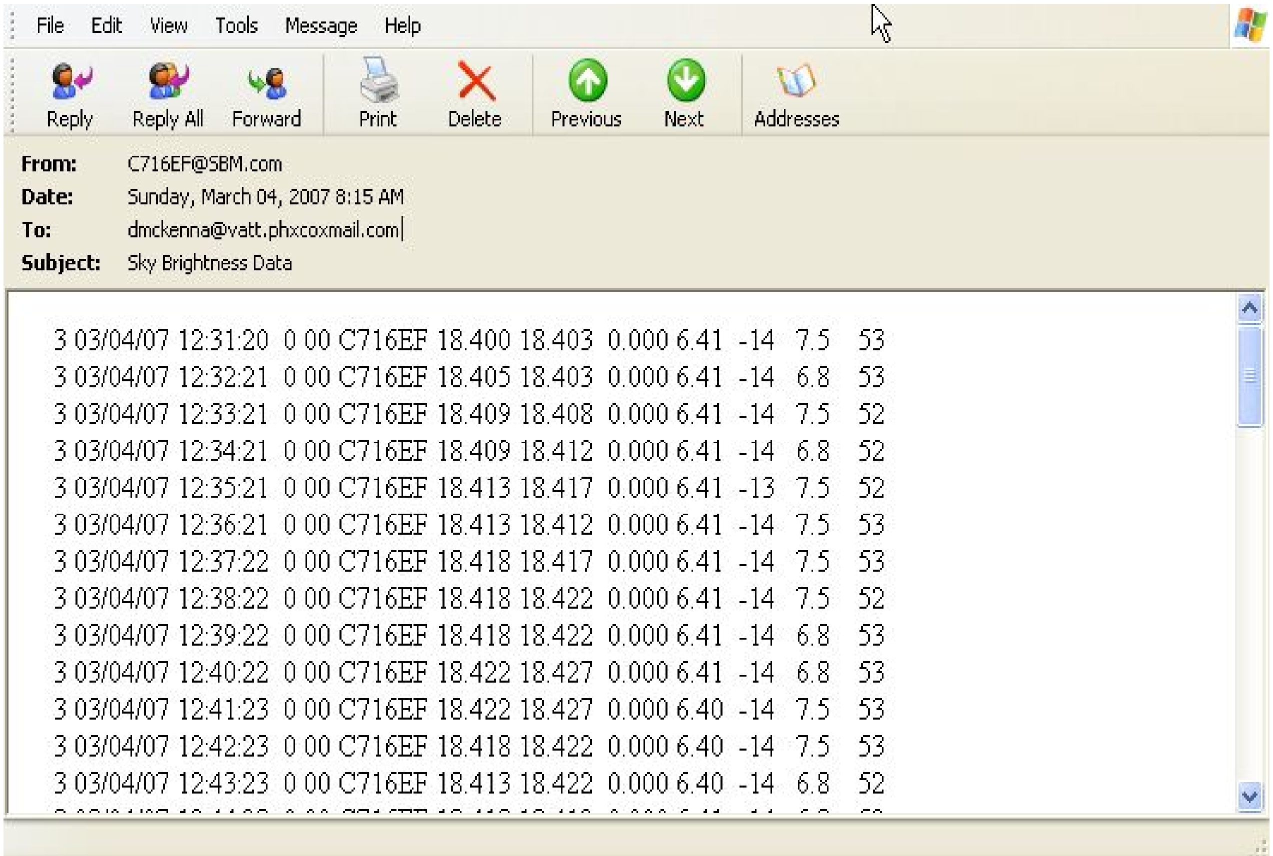
On the upper right is an XBee 2.4 GHZ spread spectrum transceiver. In open space, the range of this system approaches 300 yards. The packaged unit also adds a LCD data display useful in setup.

.



Local monitor display of data stream

In this display the data is as follows:
Unit number 2
UT date 08/17/06
UT time 17:44:19
Photometer state 0 00 the code for normal operation
Base unit serial number C726B3
First magnitude 14.045 (day time photometer was filtered)
Second magnitude 0.000 (not connected)
Magnitude 0.00 as it is a one channel measurement
Battery voltage 6.56 volts
System current + 122 milliamp (solar battery is charging)
Sensor temperature 191.2 C (sensor disconnected)
Signal strength of 55 units a strong signal

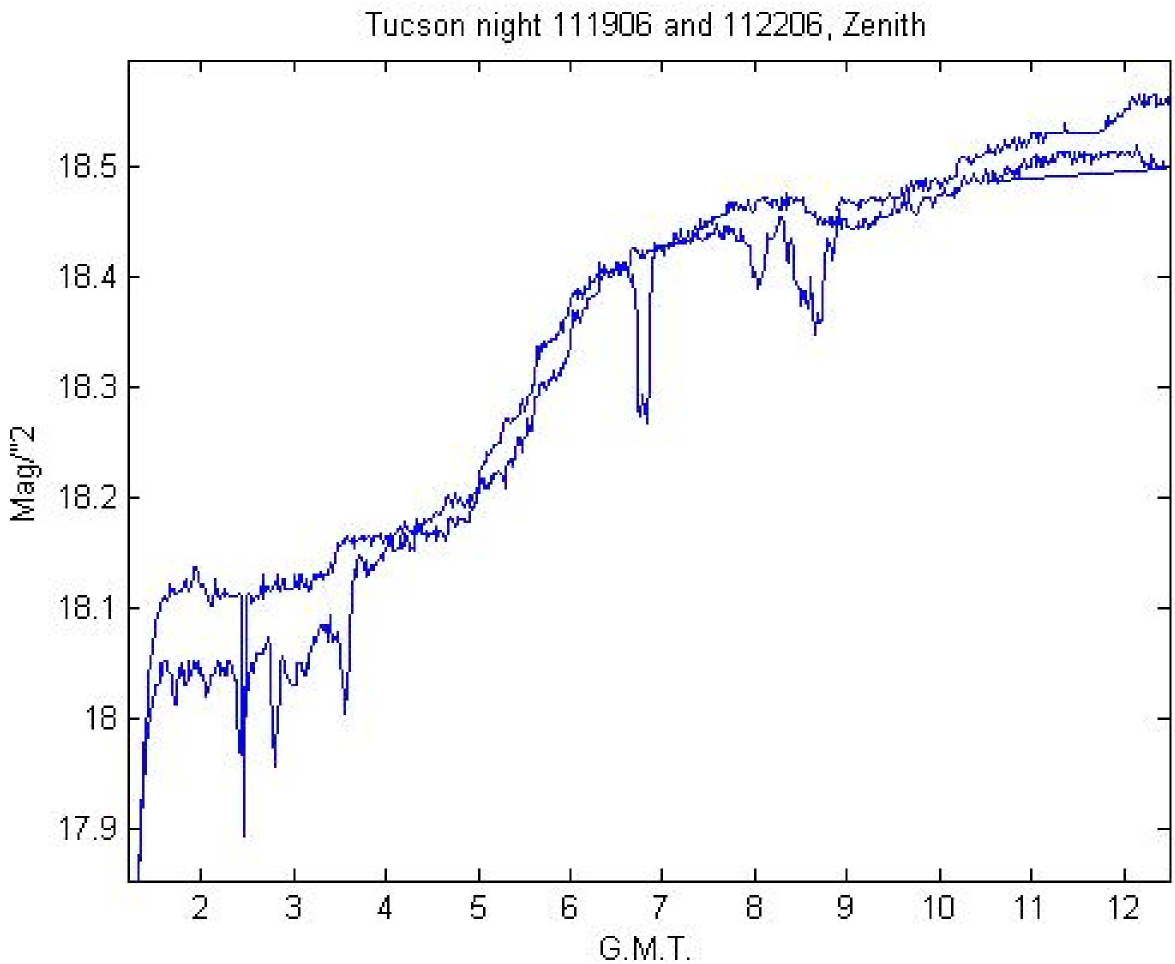


Email received at remote host

In the above system the data order is the same as the previous display. Both photometer channels are connected together to check for a difference between channels and there is none, as it should be.

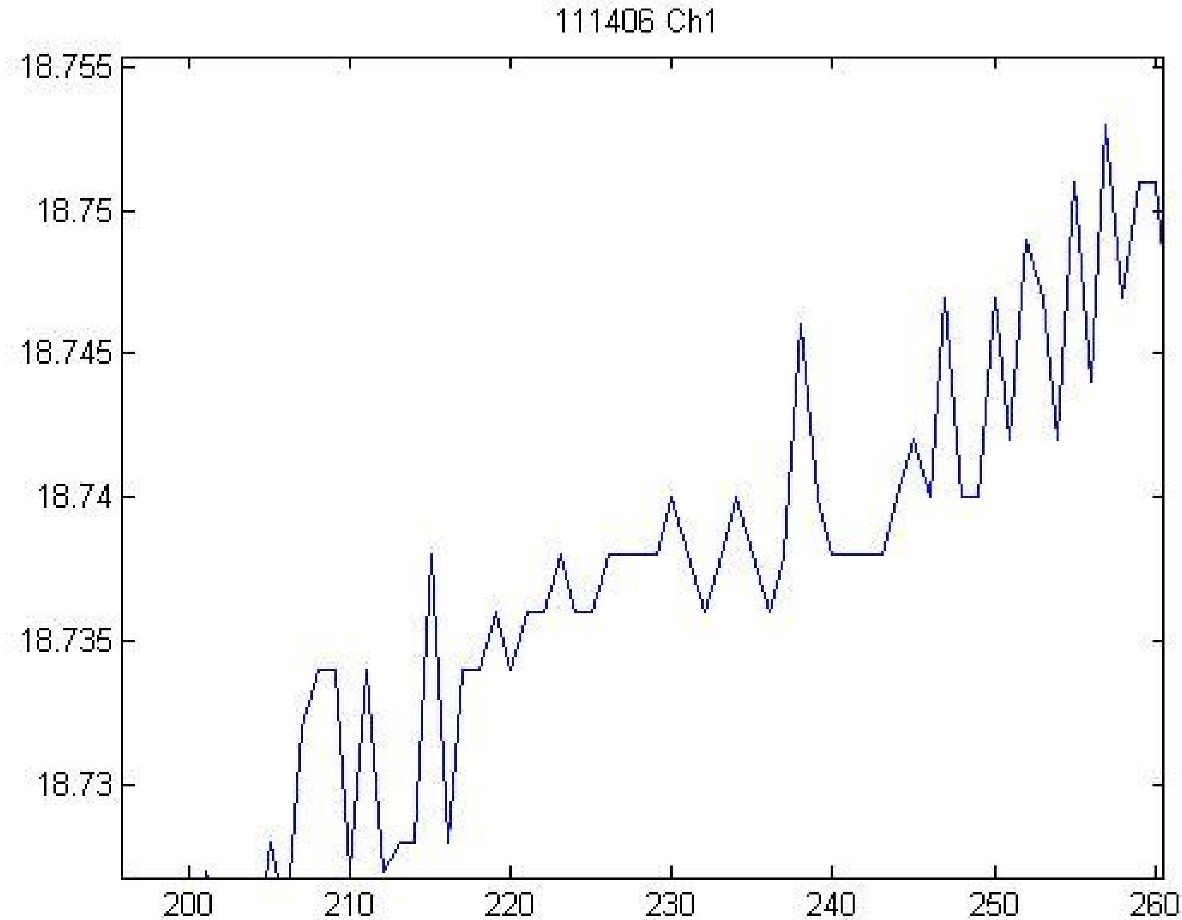
This is a night time data set and the photometer indicates a drain of 14 milliamps. The previous version had a 90 milliamp draw and was redesigned to keep the solar panel and battery size reduced. Thus our effort to maximize the power efficiency was successful.

The resolution of the sky brightness measurements is a function of the brightness measured. In Tucson the resolution is .002 magnitudes and at a dark site is about .03 magnitudes depending on the selected detector.



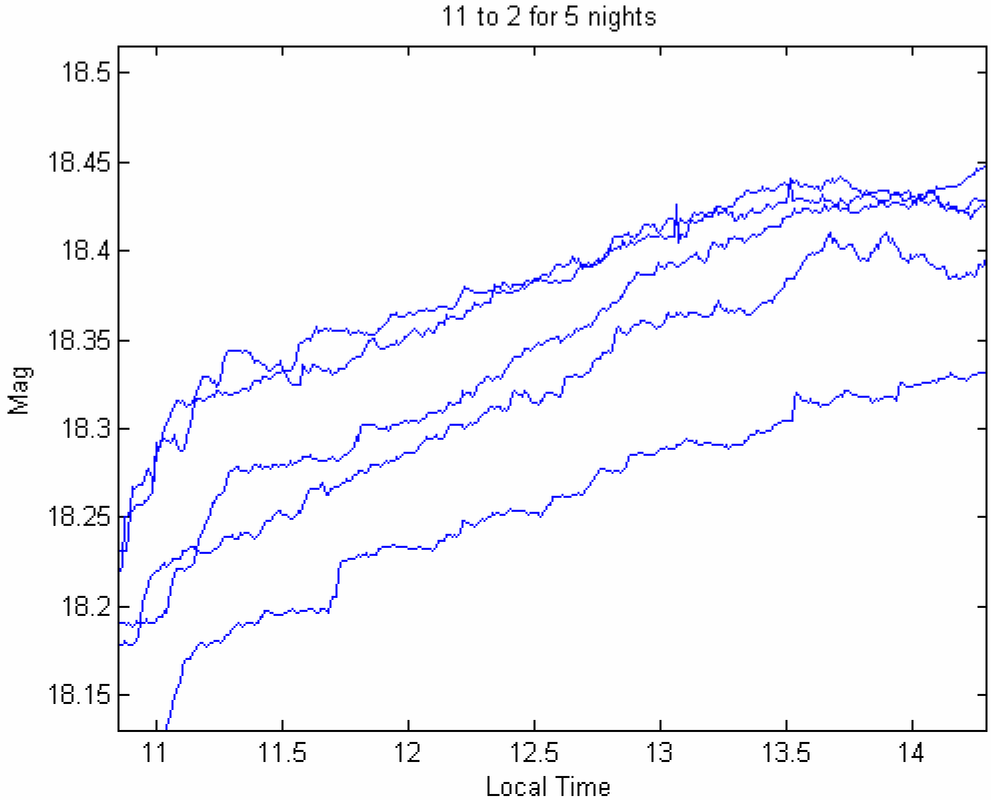
Example of zenith measurements on two different nights

At about 4 GMT the local high school turned off its stadium lights producing a jump in sky brightness. Clouds are visible between 2:30 and 4 and then between 7 and 9 GMT This data was taken in Tucson.



Detail of a zenith measurement time series demonstrating milli-magnitude resolution

In this example of an expanded scale the variations over .003 magnitudes are real and not noise. We find that in a city we can observe major light sources miles form our site and monitor changes in the timing and brightness of several sources.

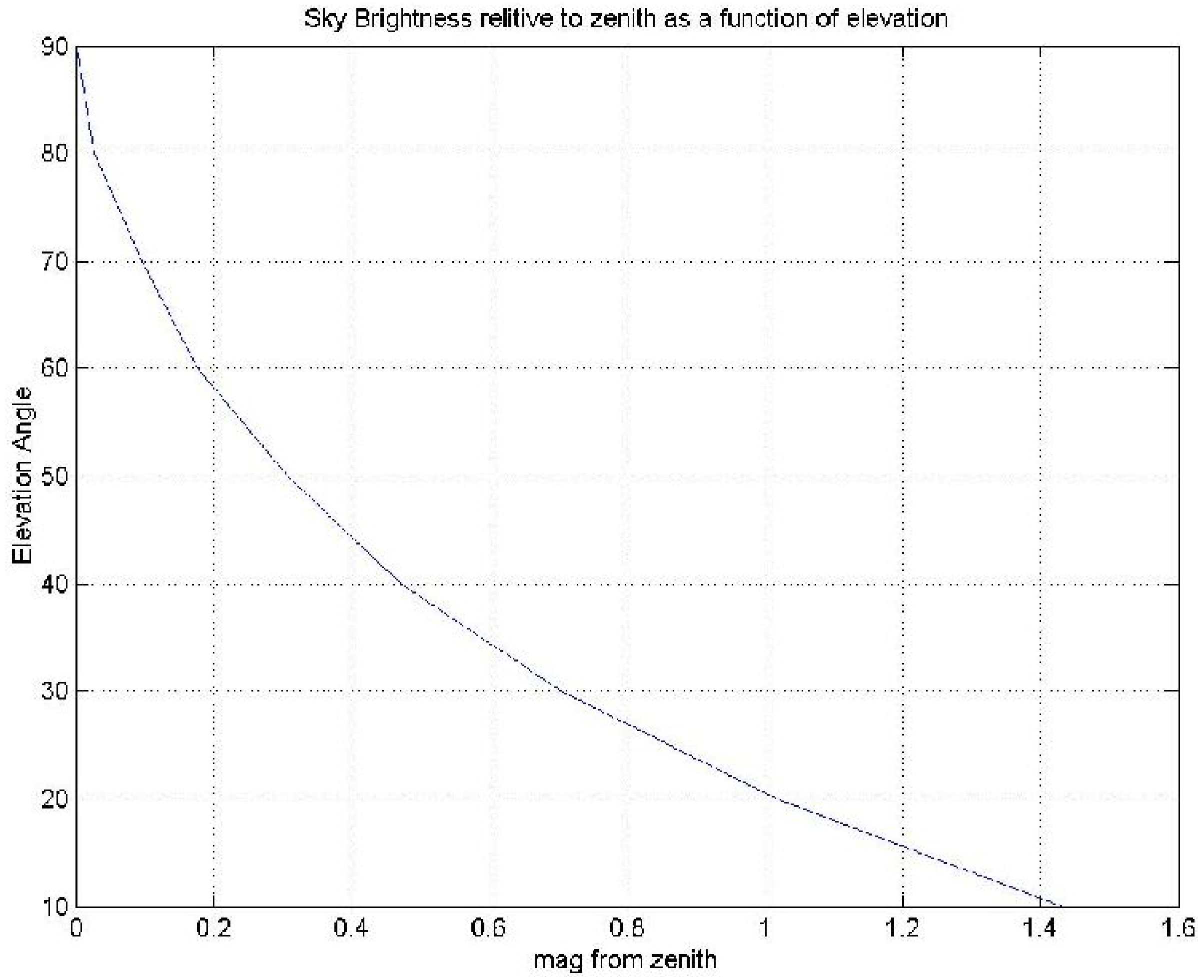


Zenith measurements over five nights

This series of measurements demonstrates that a single measurement of sky brightness is not representative of the average sky brightness. The darkening of the sky with time is thought to be the result of the evolution of the atmospheric haze layer due to the nocturnal boundary layer. The periodic wiggles may also be a signature of atmospheric gravity waves and have been noticed in the Palomar data as well.

The over all variation from night to night is due to atmospheric conditions as well. All of the above data was taken on a moonless night.

Our system uses two photometer heads. One typically is pointed to zenith and the second at an elevation angle of 20 degrees above to horizon. As will be discussed, this further makes our system unique as it measures "air pollution" as a byproduct. For long term studies the need to understand the contribution of air quality is essential.

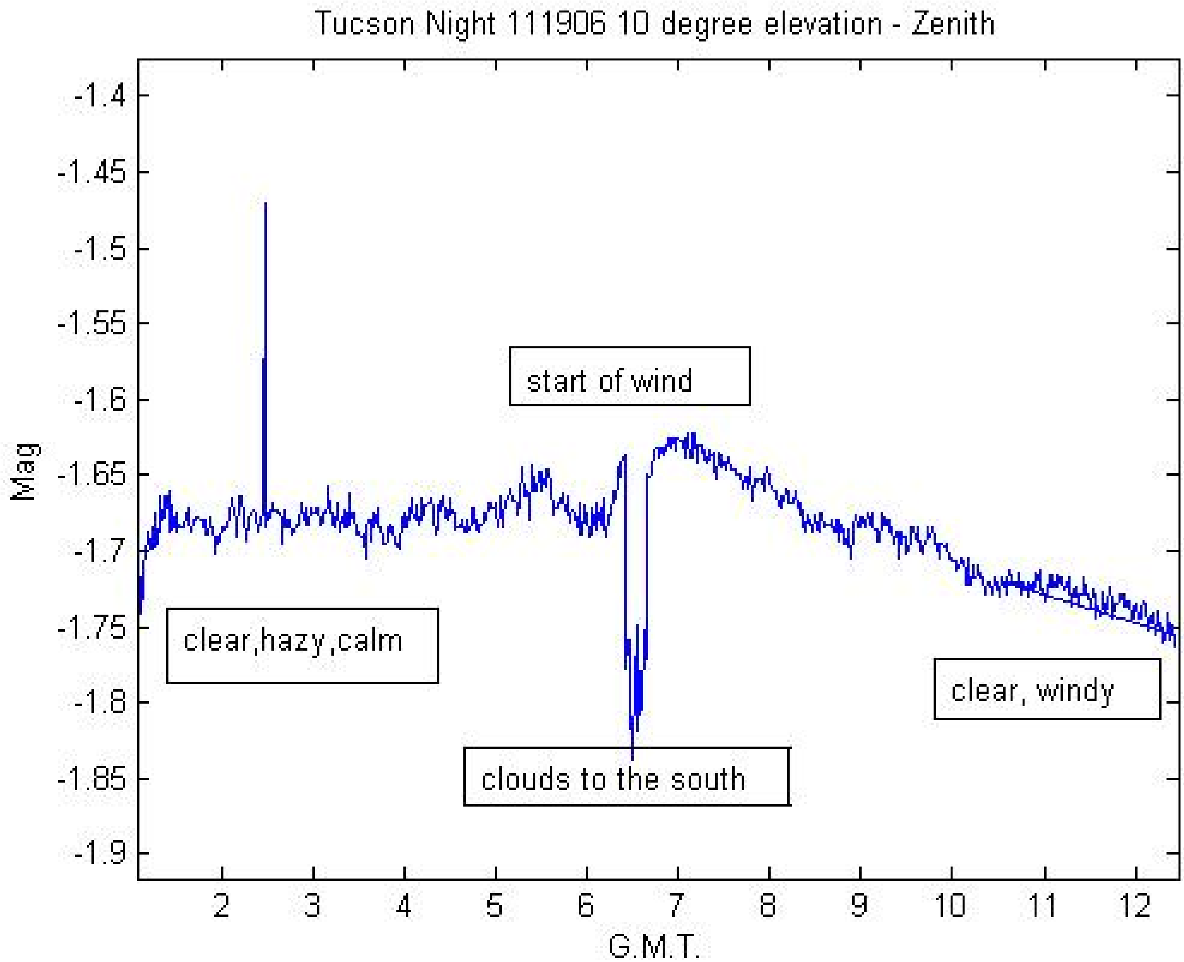


This plot of sky brightness as a function of elevation angle was obtained from the Tucson lab site. Notice that on this night the difference between zenith and 20 degrees elevation was about one astronomical magnitude.

Tucson from Kitt Peak showing the scattering layer

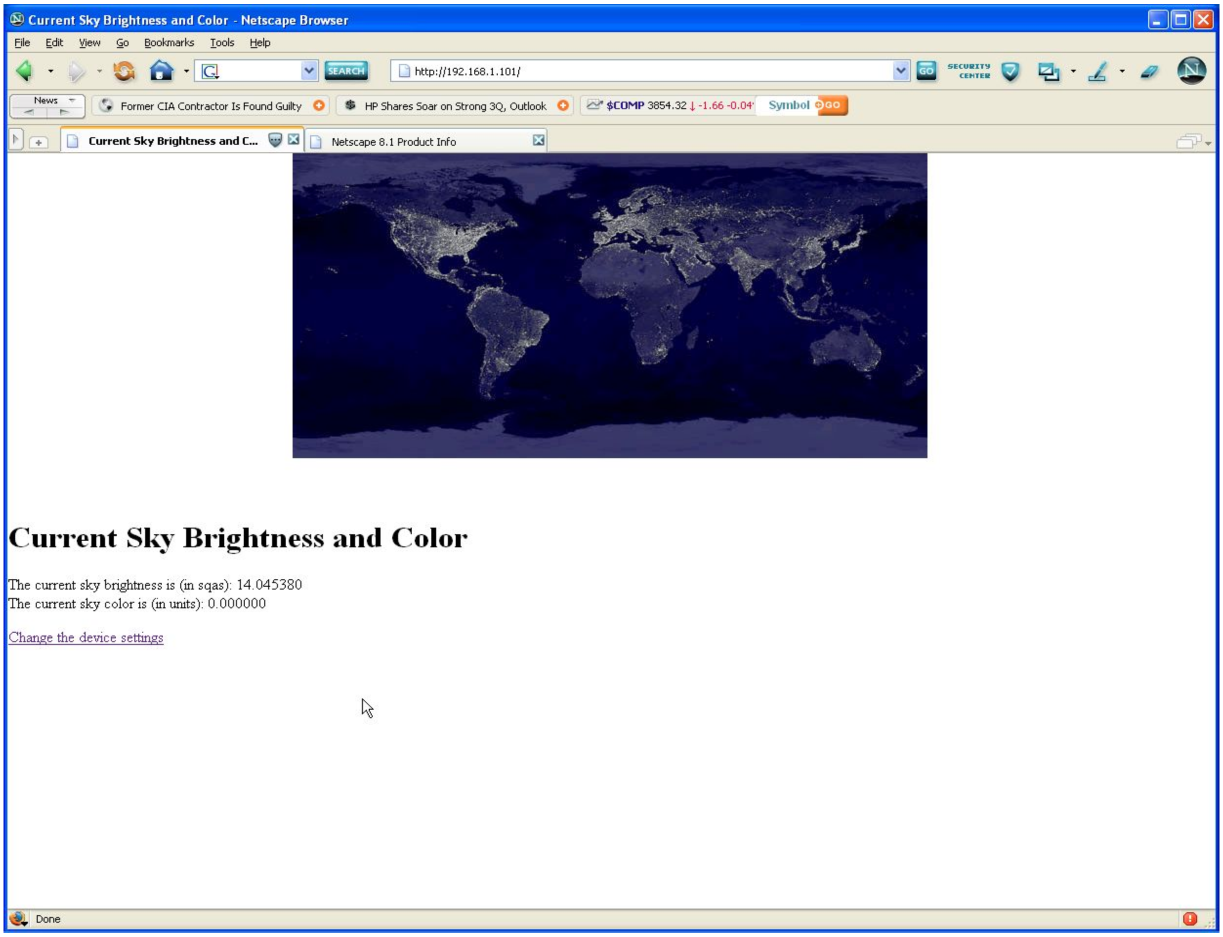
This photograph, taken in the late 60s, (?) illustrates the containment of air pollution to the altitude below the nocturnal inversion. The inversion is greatly influenced by the mountain range, wind speed and direction in non stormy weather.

Oscillations of this layer are due to atmospheric gravity waves and in part influenced by the local terrain, causing periodic variations in sky brightness. The evolution of the nocturnal drainage flow from the local mountains can not only reduce the height of this layer but wash it out and away from the Tucson area so that the air quality in some parts of the region become better over the coarse of the night.



Difference in sky brightness measured at two elevation angles as a function of time

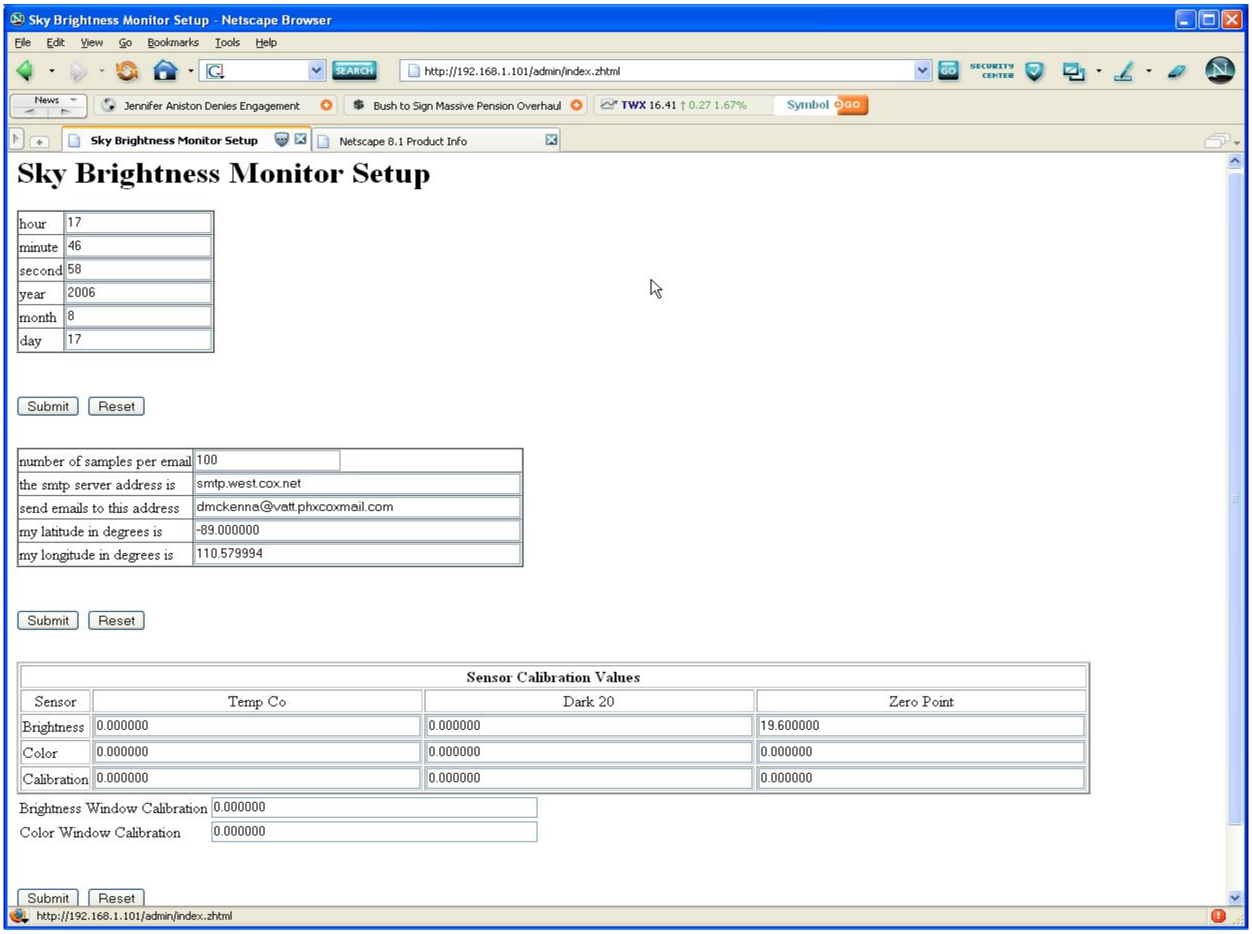
This plot is of the difference in brightness between zenith and 20 degrees elevation over a night where the winds picked up a cleared out most of the haze layer that built up during an extended period of time dominated by high pressure. As the air clears the zenith gets darker relative to the low elevation angle measurement.



Web Page Interface

When the system is initialized it searches via DHCP for an available IP address. When it connects to the net it will go out and find a time server to calibrate the time standard. The LCD displays the IP address to the user. The user then directs a standard web browser to the address indicated and logs in with the user name and password supplied with each unit.

At any time the local user can log in to change setting or view the current data and command a system reset or download of saved data.



Web Page interface for site and detector setup

The setup page allows the calibration data to be entered for each detector. In this way updated detectors can be placed in to an existing system to continue data collection within the accuracy of the calibration system.

The site latitude and longitude is used by the onboard clock to sample based on the sun elevation angle and tracks the length of the night throughout the year.

The user can also set:
Number of samples per email
SMTP server address
Remote data collection host email address

Current Status:

The prototype NSBM has been running at two sites for about a year. Site one is located in Wisconsin to test winter conditions, and site two was located in Tucson Arizona and now located on Palomar Mountain California. Units at both sites continue to function giving us confidence that the current draw, battery size and solar panel capacity are properly sized.

During the Palomar and Tucson exposure test we encountered various forms of detector window contamination due to dust, birds and insects.

Certain birds will perch on the remote unit and sometime their droppings contaminate the front window. We also experience the detector baffle tubes being used as food storage. We are now experimenting with a barbed wire deterrent around the baffle tubes and across the solar panel.

The detector windows are not anti-reflection coated so that repeated cleaning does not change to transmission characteristics of the front window.

We will develop a calibration program where detectors are sent to replace field units for recalibration. This effort will result in an extensive data base on calibration drift. We will also issue a protocol insuring standard window care.

Technical aspects of the NSBM development:

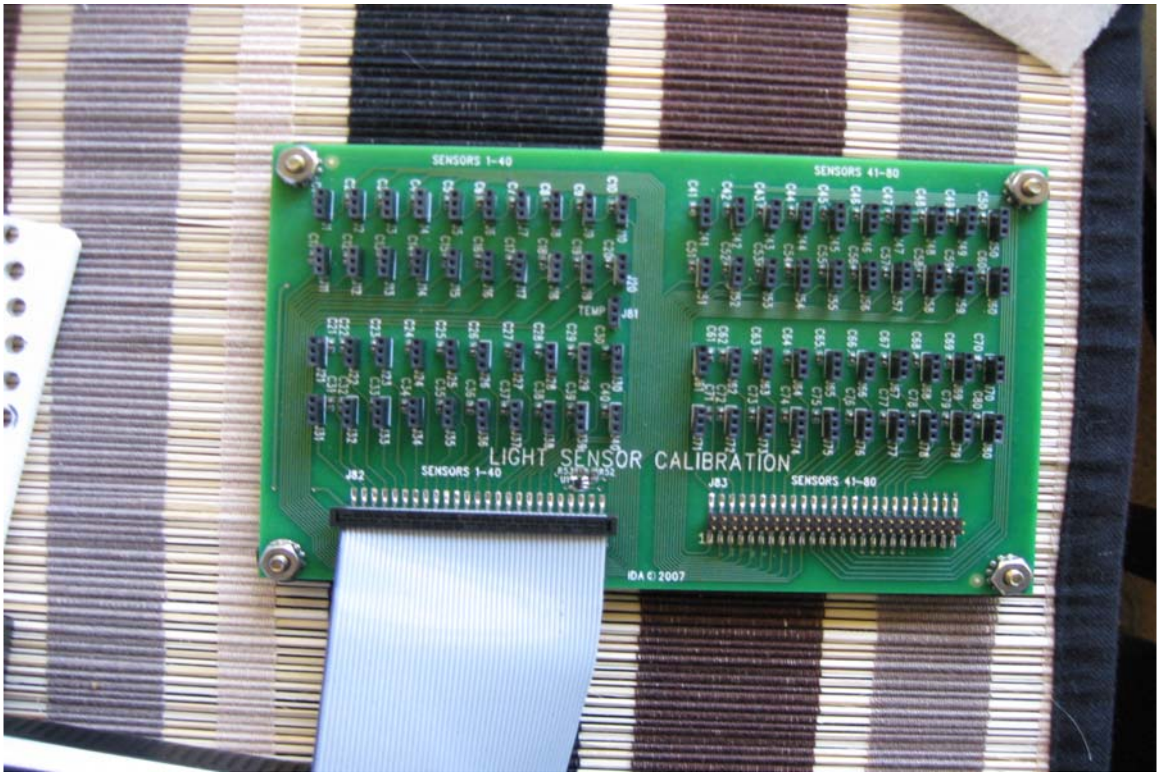
The Basic goal is for on sky measurement accuracy to plus or minus 1% over the life of this program.

Our approach is to build a cost effective, robust and stable system suitable for a long term measurement campaign. Our goal is to monitor the global night sky over a period of thirty years.
The technology will evolve rapidly during this time and for this project to succeed, we must track the technological evolution.

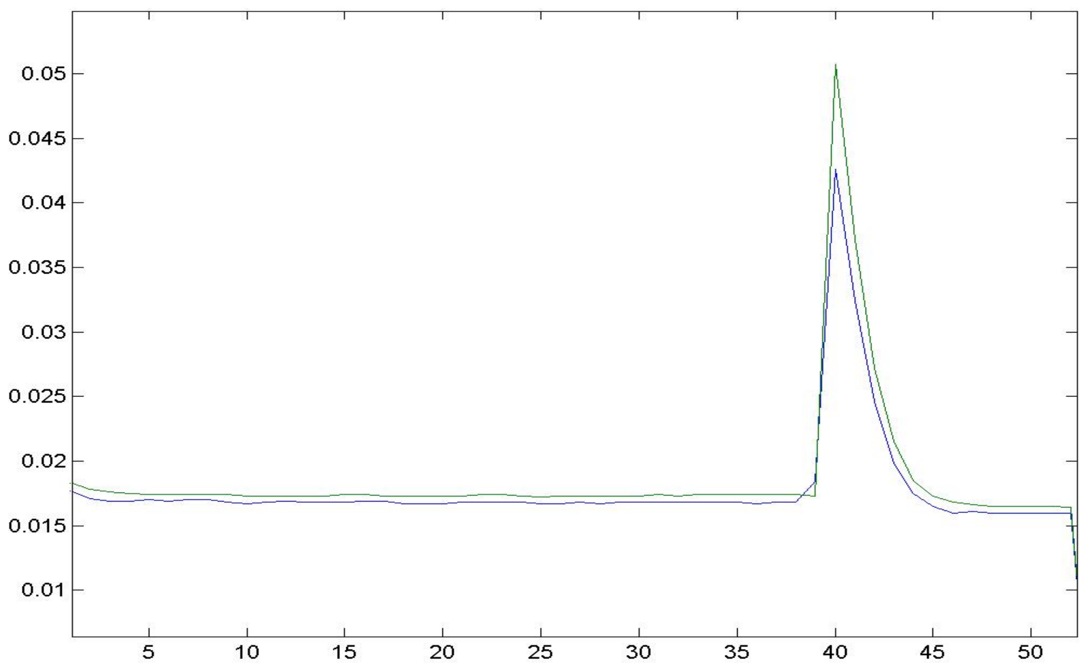
Crucial to the long term success and acceptance by the scientific community, is the standardization of calibration. The most important aspect of our program is to deal with lifetime issues and product cycle limitations.

Calibration process:

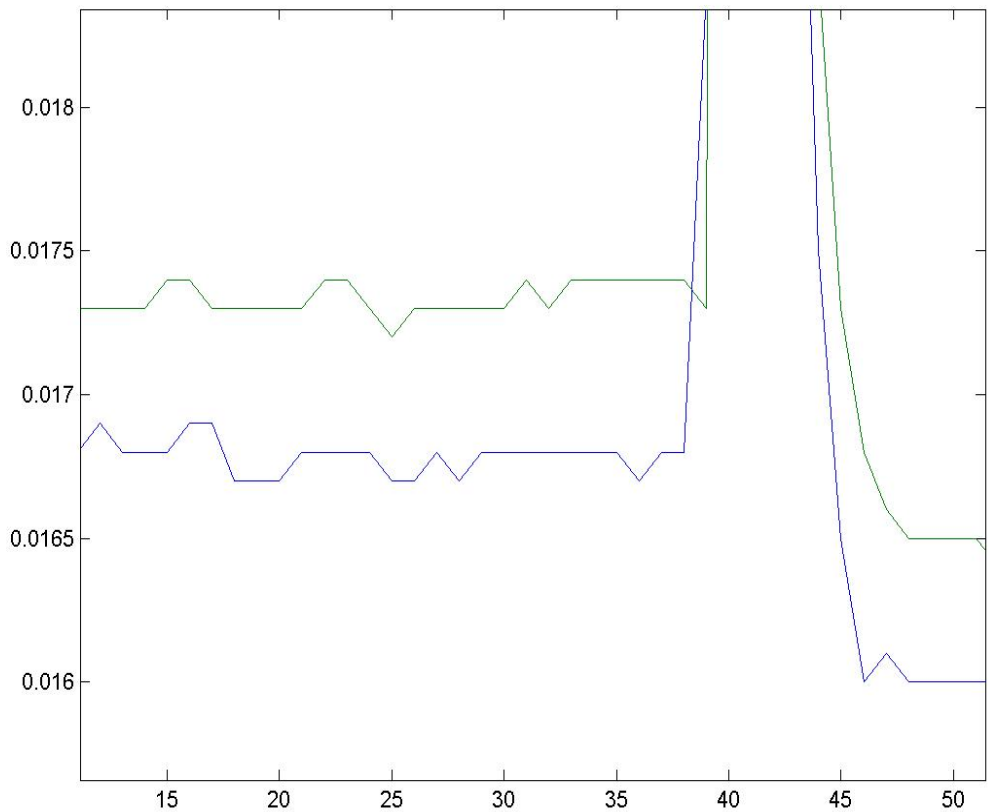
The characterization of the detectors used yields about 10 % of the tested devices suitable for field deployment due to the wide variation of dark count rate temperature coefficients. Thus careful screening is required to select detectors that meet our requirements.



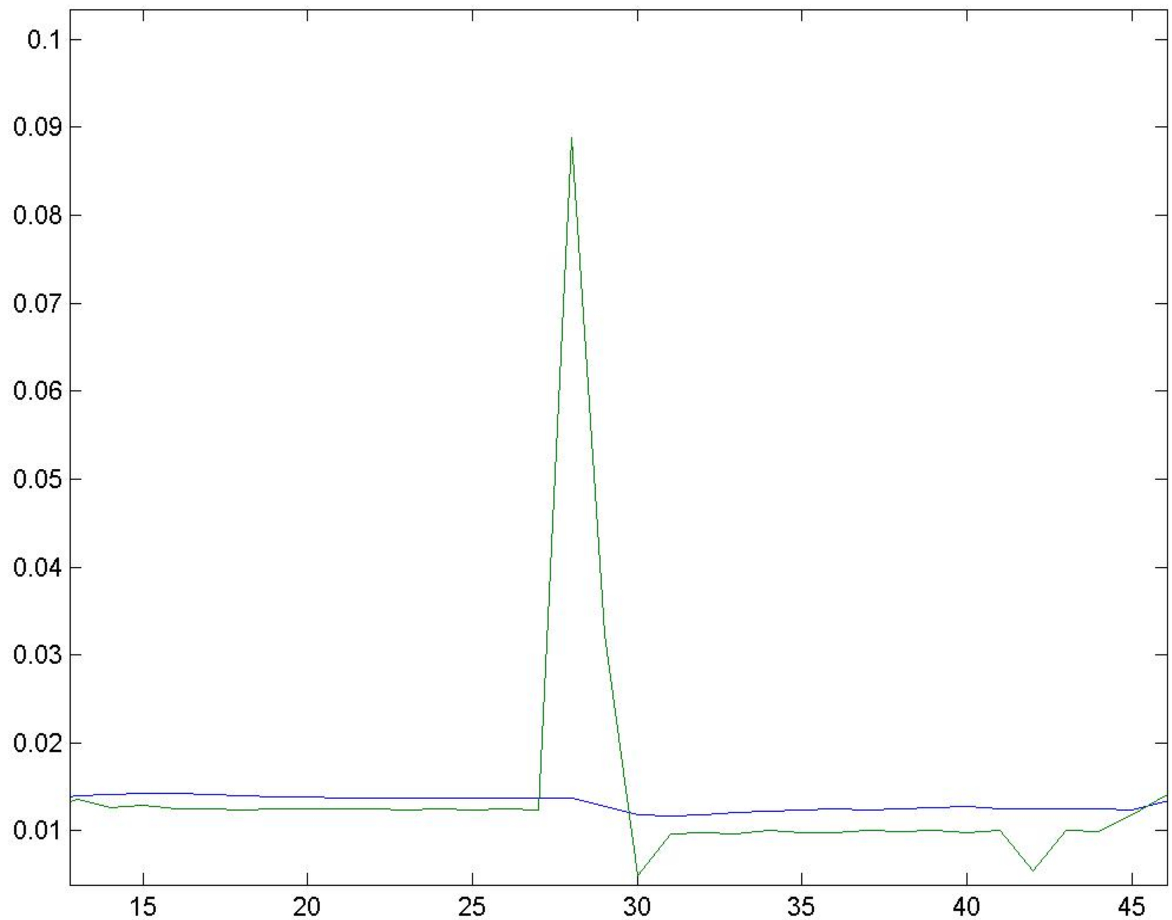
New sensor calibration board 80 channels total



Two detectors in the dark and free air subjected to a 20C temperature step



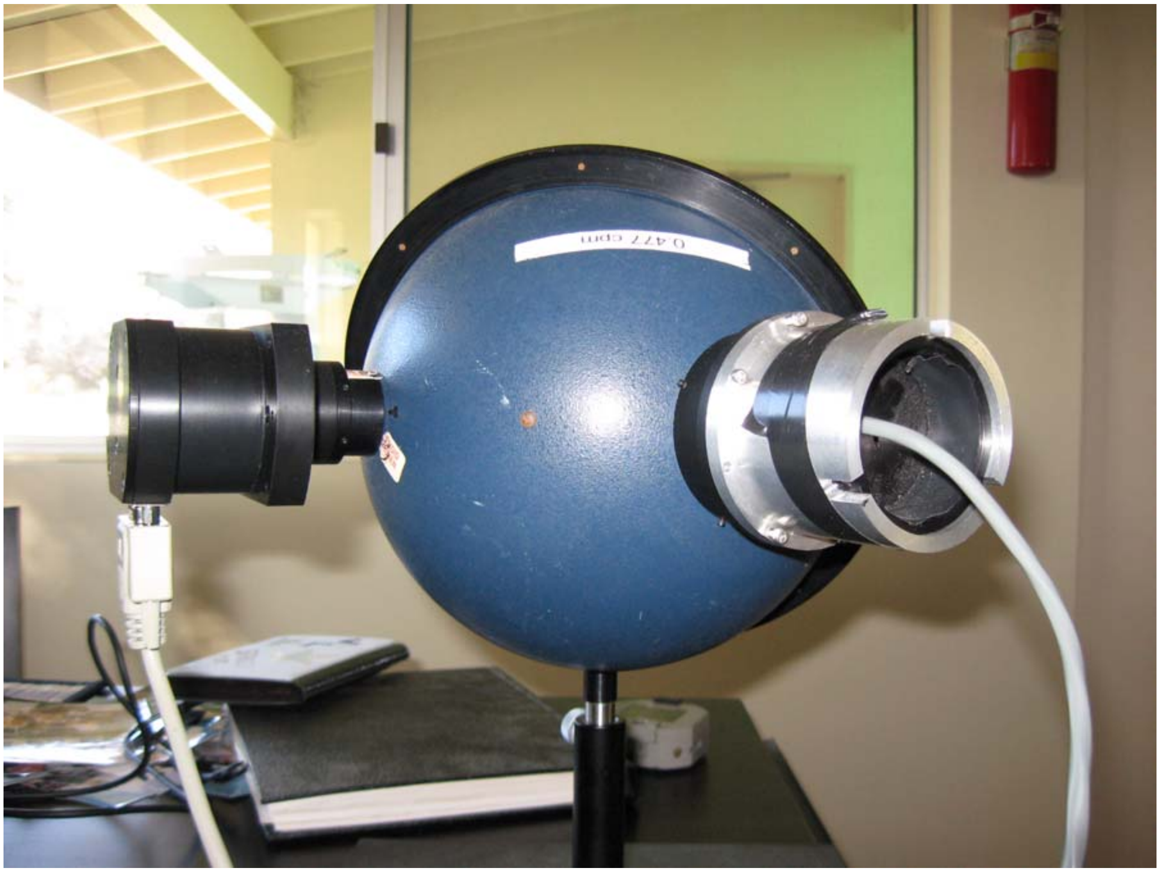
Detail of Temperature Step Data



Temperature step data of a free air detector and a thermally bounded detector

Potting the detector to thermally bond it to the photometer head housing almost entirely eliminates the offset due to temperature rate of change.

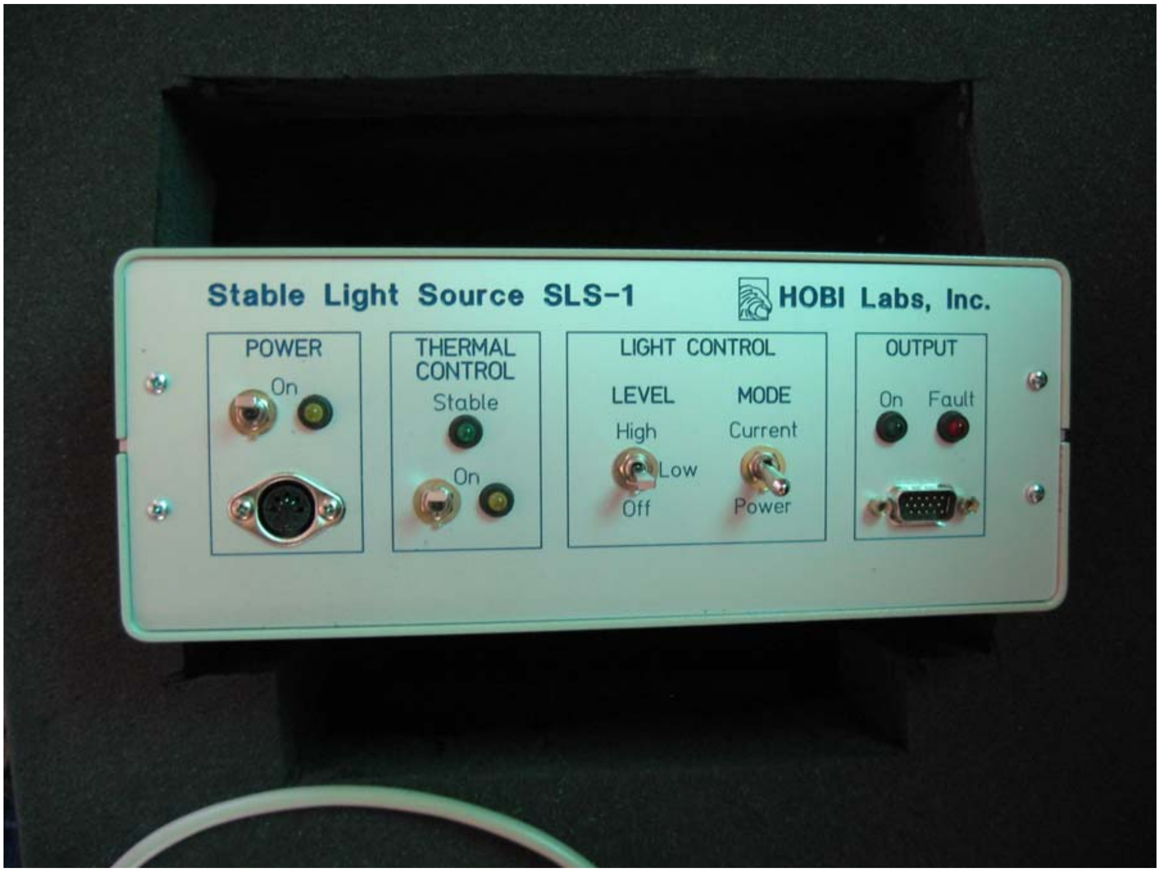
In addition, each assembled device is flux calibrated by a standard light source. The stable light source is regulated to a short term stability of 0.1%. A series of reference detectors is used to monitor the long term stability of this source. Over the past three months we have not been able to detect systematic drift to 1 part in 1000



Calibration sphere with stable light-source on the left and detector under test inserted on the right

The integration sphere is used to provide a uniform light source for photometer head zero point calibration. This is the basis of our network and once the master unit is calibrated it will be handled with care.

We expect to build several units to use for comparison with our main reference units. This method should result in the ability to sustain our calibration to better than one percent over the lifetime of this project.



Control unit for stable light-source

Need to Standardize:

Recently the National Park service has co-observed with their system and one of our detector heads with a custom readout. Preliminary data shows fair agreement between the two photometric systems and more data and careful analysis will need to be performed before a critically reviewed appraisal can be published.

This is the most critical part of this process.

Acceptance of our device by the park service for long term environmental studies is the fastest track to commercial success.

The process of peer reviewed calibration and standardization with a large multi decade data base of sky brightness and with the stability of our calibration process is our main product. The technology evolution if properly tracked will over time, increases this device cost / performance index.

Thus the NSBM program will need to reinvest in the development of this type of instrumentation over the life time of the project.

Because the volume of this device is low enough to be a problem for mass production, by maintaining the ownership of the IDA magnitude system and the reputation of our attention to calibration we will have our best chance to compete with any commercial challenges.

Effort need to proceed:

Calibration

The continued collaboration with the National Park Service, and initial distribution heavily weighted towards major Observatories. Observatories have an interest in the validation of calibration and also have users well versed in astronomical instrumentation.

Expansion of the calibration facility

I have been able to calibrate 10 detectors at a time. We have constructed but not yet deployed the fixtures to calibrate up to 80 detectors simultaneously. Our goal is for 160 units per test.

This will require renewing our national instrument development system and about a three month of intensive effort on my part.

Minor software development of NSBM

We have identified a few minor changes need for deployment. This may be a 1 week effort at most by Matrix.

Web based data collection and display

The first data collection system needs to be developed to ingest, process, archive and display the NSBM data stream.

Development of support infrastructure

To support a large scale release we need to have people trained in the support of these devices including.
Shipping and receiving include issues of export and import.
Customer support, problem tracking and resolution.
Data analysis, public relations and user training.

Proposal:

We propose to have Matrix deliver to the Palomar site 25 units in the time span of a month if possible.

Resources will me needed on the order of $10,000 for parts and supplies to construct and test the detector heads including an expanded test facility to be completed at the Palomar site. This will be a two to three month process and units will be produced as this occurs to continue initial product flow.

Palomar has a member of the programming staff who is interested in development of our data collection host computer and will require compensation for his efforts.

Test site selection to include, South and North American Observatory sites.

Intensive planning and commitment of production facilities at Tucson Headquarters be finalized.

Matrix will be contacted this next week for a product description package that I will augment with final text and illustrations.

Possible Options to explore:

NSBM as a service:

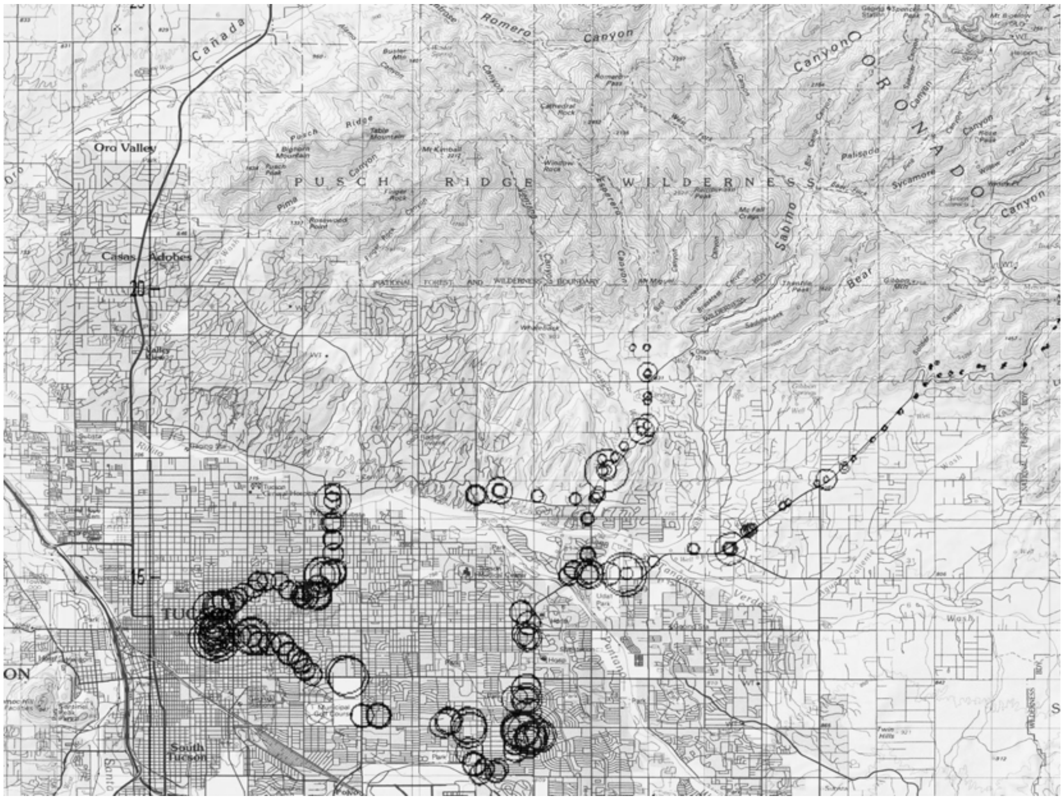
One possibility is to lease our devices to potential commercial studies so that we retain our photometers and supply them with reports.

NSBM distribution:

For a Global network the political climate in the U.S. may make it difficult to export our device to certain regions of the world that could undergo rapid development.
Thus basing our operation in a country like New Zealand may reduce this limitation and have lower operating costs.

Expand our techniques for mobile data collection:

We have also used this photometer system with a GPS to map sky brightness as a function of location. These devices have the ability to accept an on-board GPS chip And can function without the base unit for a few nights. In practice these mapping units would be produced without the solar battery and have wall chargers. After a drive the remote unit can be brought within 300 yards of the base to download the data



Map of Tucson with brightness of sky displayed with a linear scale where diameter is proportional to brightness