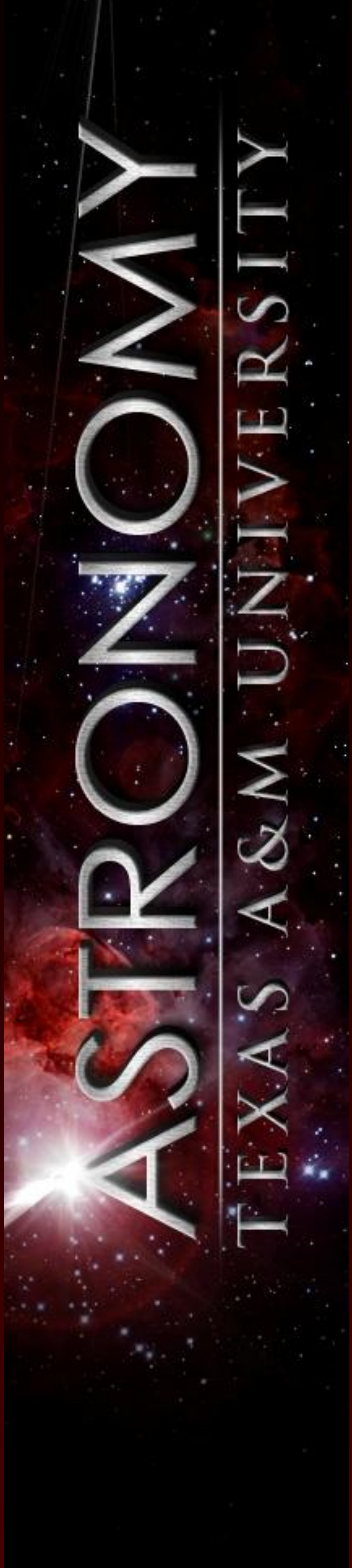

A New Instrument to Measure Nighttime Sky Brightness

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Abstract

We have designed and built a wide field photometer to measure the inherent brightness of the night sky. The device consists of a single lens and photodiode with a wide bandpass and a field of view of 11.2 square degrees. The total signal over this field is integrated and averaged to produce a value of luminosity per square arcsecond. The large field size reduces the relative contribution from individual stars, but care should be taken to avoid the brightest (m<=2) objects in the night sky. High frequency signals are heavily filtered to minimize white noise so that the system can maintain high photometric accuracy to as low as m=21.5 per square arcsecond. Nonetheless, the system can easily acquire a measurement every second to catch even sudden changes in sky luminosity.

Introduction

Every astronomical measurement taken from the ground is affected by background radiation from the night sky. Light pollution, stray light scattered or reflected from excessive city lighting, plays a large role in determining the brightness of the night sky. However, the sky is never completely dark even in the absence of artificial lighting. Scattered starlight, zodiacal light, and thermal emission from the atmosphere itself ensure that even the most remote sites have some inherent sky brightness. Thermal emission from atmospheric gases—Airglow—is the largest component of this natural sky brightness and has been shown to vary on timescales as short as a few minutes to eleven year periodic variability tied to the solar cycle. This variability can be as strong as half a magnitude per square arcsecond, a factor of roughly 60%. To further complicate matters, scattered moonlight has a strong effect on sky brightness and this effect varies with angular proximity to the moon. Sky luminosity is thus determined not only by geographical location, but by where and when one measures the night sky. It is therefore important to have an accurate understanding of how sky luminosity varies as a function of time, position, and proximity to bright objects in the night sky.

Design Considerations

- An 11.2 deg^2 field of view was selected to integrate signal over a large area of sky while avoiding the brightest stars. The contribution of individual dim stars is minimized by averaging over a large patch of sky.
- Sky brightness varies considerably from site to site, so a large dynamic range (the ratio between the smallest and largest useful measurement we can take) was necessary to measure the faintest skies available without reaching saturation on moonlit nights or under city/suburban skies. The instrument has a dynamic range of 750 or about 7.2 astronomical magnitudes.

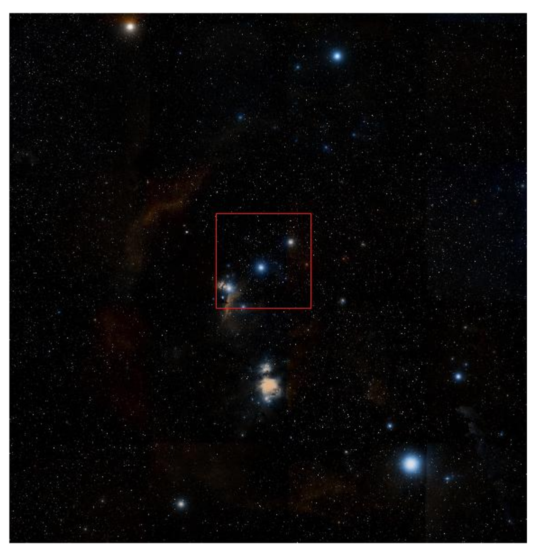

Fig. 1: The field of view (in red) is compared with the constellation Orion. Image via DSS.

Electronics and Optical Design

This instrument is based around a simple optical system consisting of a single fast converging lens and a photodiode detector. The photoelectron current is converted into a voltage by internal electronics and high frequency noise is removed with a series of passive and active low pass filters. The final output is fed to a USB data acquisition device for digital storage. All data are instantaneous measurements of a voltage which corresponds to the flux incident on the lens at that moment.

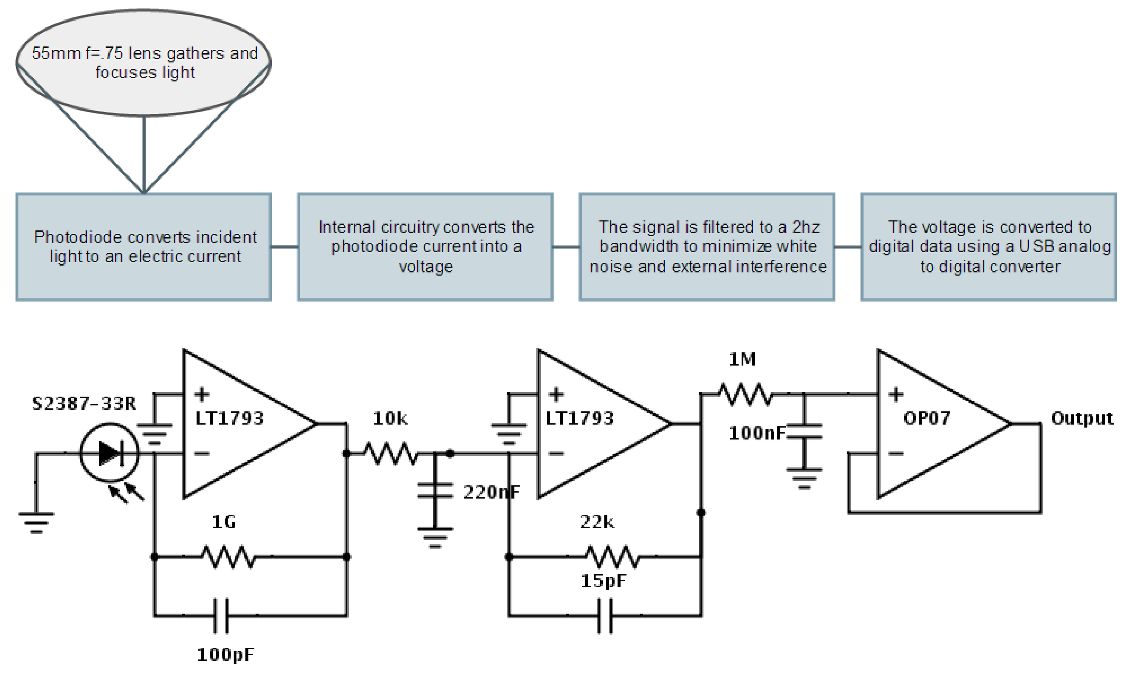

Fig. 2: A simple explanation of the instrument with a schematic of the internal circuitry.

Magnitudes And Calibration

The inherent brightness of the night sky varies as a function of wavelength. Since we measure a wide bandpass (350nm to 1000nm) it is important to consider the color variance of sky brightness. To this end we use color information from the literature to estimate the flux contribution of each bandpass for a given V magnitude. We also consider the instrumental throughput as measured by a series of calibrated laser sources. Combining these two factors we predict the total signal measured for a given V magnitude and define an instrumental magnitude such that m = 20/arcsec^2 corresponds to 9.74e7 counts per second and a system output of 34.4 mV.

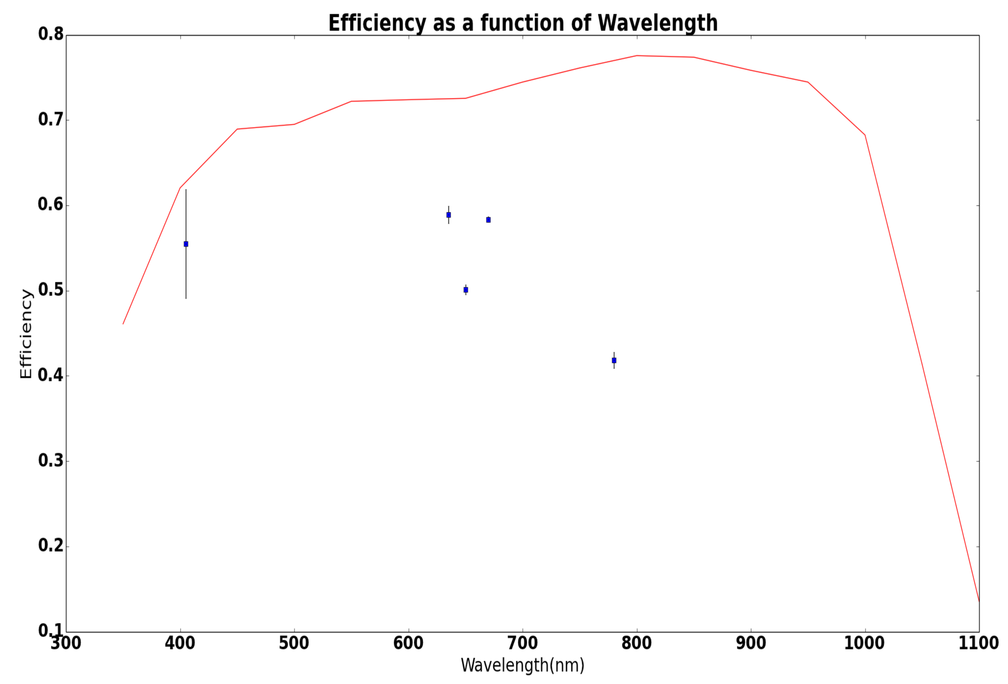

Fig. 3: Instrumental throughput (blue) as a function of wavelength. The sensitivity of the photodiode is plotted in red based on the manufacturer's specifications.

Performance

Instrumental precision was measured by taking a series of sixty measurements at a rate of 1hz under constant illumination. The standard deviation was taken as a measurement of noise and is plotted below as a function of sky brightness. It is worth noting that instrumental noise was relatively constant at around 2 mV and that much of the uncertainty for brighter measurements is due to a gradual voltage drift for outputs on the order of a few volts. If this is corrected for we can expect to match the predicted signal to noise ratio for the full dynamic range of the instrument.

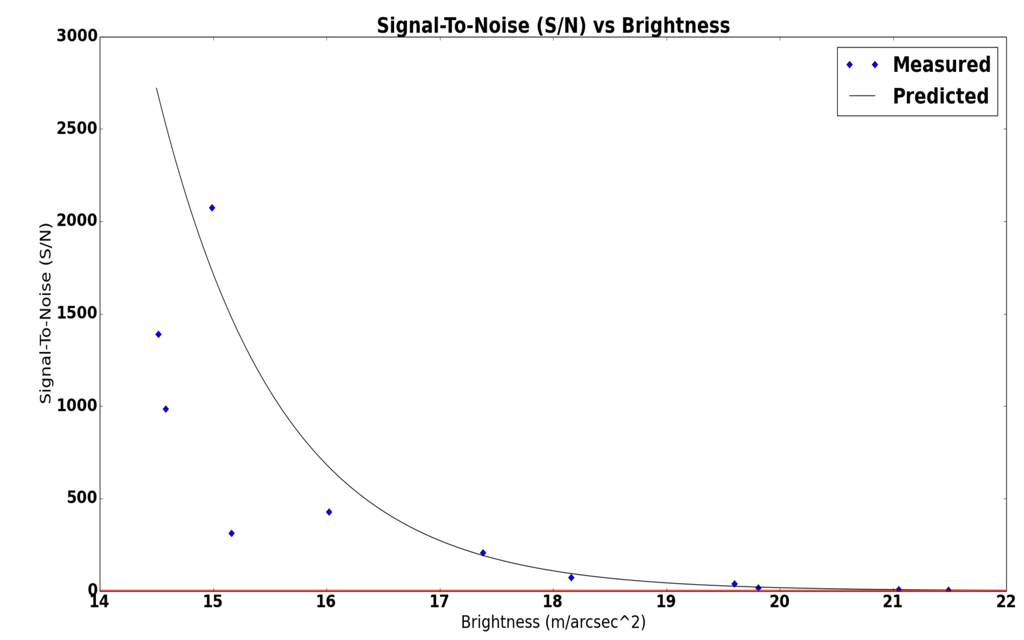

Fig. 4: Signal-to-noise ratio as a function of sky brightness. The low data points at m<16 are due to a gradual voltage drift for signal outputs on the order of a few volts.

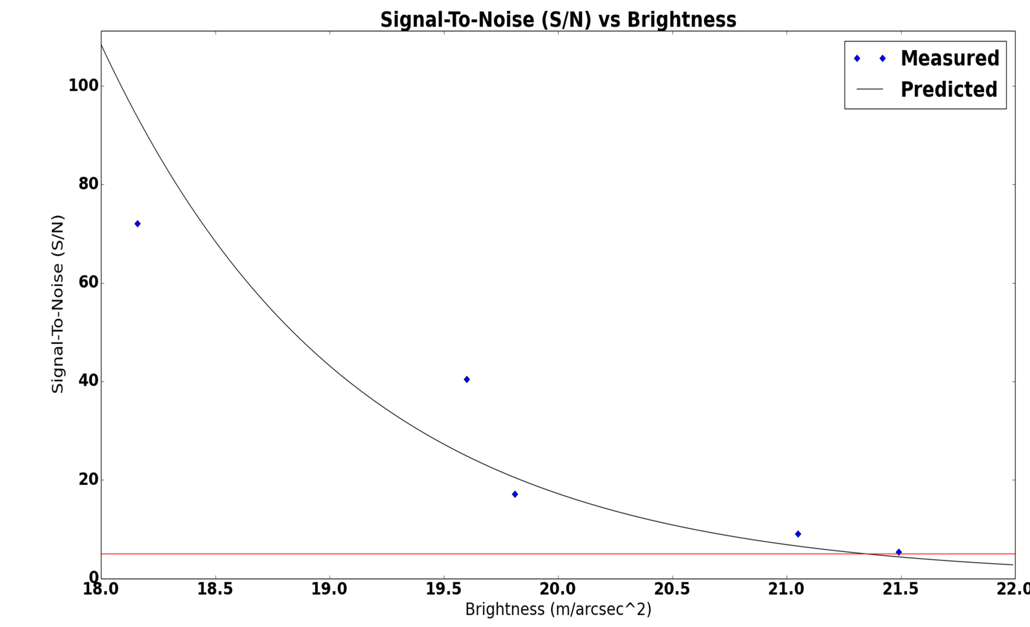

Fig. 5: Signal-to-noise ratio as a function of sky brightness. The red line indicates a signal to noise ratio of five.

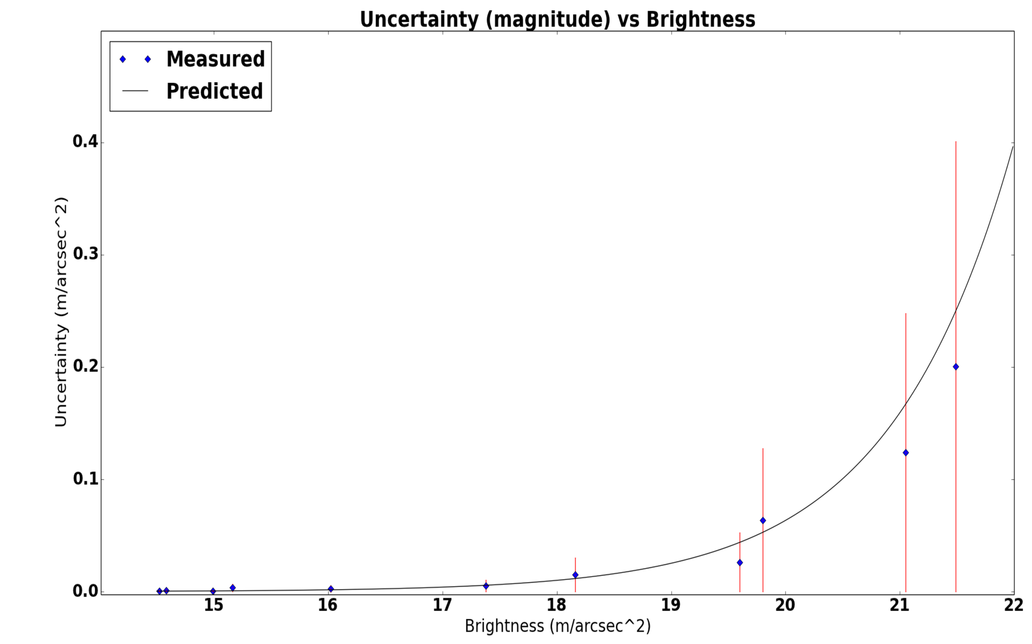

Fig. 6: Uncertainty (in magnitudes) as a function of sky brightness. Uncertainty increases dramatically for skies fainter than m = 21.5/arcsec^2.

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