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SWIR HEMISPHERICAL AIR-GLOW PLOTTING SYSTEM SHAPS: POSTPRINT

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14. ABSTRACT
It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (-85km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band of wave length 0.9 to 1.7 um. Numerous studies of these phenomena have demonstrated that the irradiance shows significant temporal and spatial variations in the night sky. Changes in weather patterns, seasons, sun angle, moonlight, etc. have the propensity to alter the SWIR air glow irradiance pattern. By performing multiple SWIR measurement at a mosaic representation of the celestial hemisphere was constructed and used to investigate these variations over time and space. The experimental setup consisted of two sensors, an InGaAs SWIR detector and a visible astronomical camera, co-located and bore sighted on an AZ-EL gimbal. This gimbal was programmed to view most of the sky using forty five discrete azimuth and elevation locations. The dwell time at each location was 30 seconds with a total cycle time of less than 30 minutes. The visible astronomical camera collected image data simultaneous with the SWIR camera in order to distinguish SWIR patterns from clouds. Data was reduced though batch processing producing polar representations of the night sky irradiance as a function of azimuth, elevation, and time. These spatio-temporal variations in the irradiance, both short and long term, can be used to validate and calibrate physical models of atmospheric chemistry and turbulence. In this paper we describe our experimental setup and present some results of our measurements made over several months in a rural marine environment on the Islands of Kauai and Maui Hawaii.

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SWIR Hemispherical Air-Glow Plotting System
SHAPS

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Abstract

It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band of wave length 0.9 to 1.7 µm. Numerous studies of these phenomena have demonstrated that the irradiance shows significant temporal and spatial variations in the night sky. Changes in weather patterns, seasons, sun angle, moonlight, etc have the propensity to alter the SWIR air glow irradiance pattern. By performing multiple SWIR measurements a mosaic representation of the celestial hemisphere was constructed and used to investigate these variations over time and space. The experimental setup consisted of two sensors, an InGaAs SWIR detector and a visible astronomical camera, co-located and bore sighted on an AZ-EL gimbal. This gimbal was programmed to view most of the sky using forty five discrete azimuth and elevation locations. The dwell time at each location was 30 seconds with a total cycle time of less than 30 minutes. The visible astronomical camera collected image data simultaneous with the SWIR camera in order to distinguish SWIR patterns from clouds. Data was reduced through batch processing producing polar representations of the sky irradiance as a function of azimuth, elevation, and time. These spatio-temporal variations in the irradiance, both short and long term, can be used to validate and calibrate physical models of atmospheric chemistry and turbulence. In this paper we describe our experimental setup and present some results of our measurements made over several months in a rural marine environment on the Islands of Kauai and Maui Hawaii.

1.0 INTRODUCTION

Air glow from chemical luminescence in the upper atmosphere has been observed at a number of different wavelengths [1-3]. In the short wave infra-red (SWIR) between 0.9 and 1.7 µm it is due to emissions from hydroxyl radicals transitioning from excited rotational and translational states to lower energy states and emitting a SWIR photon in the process.

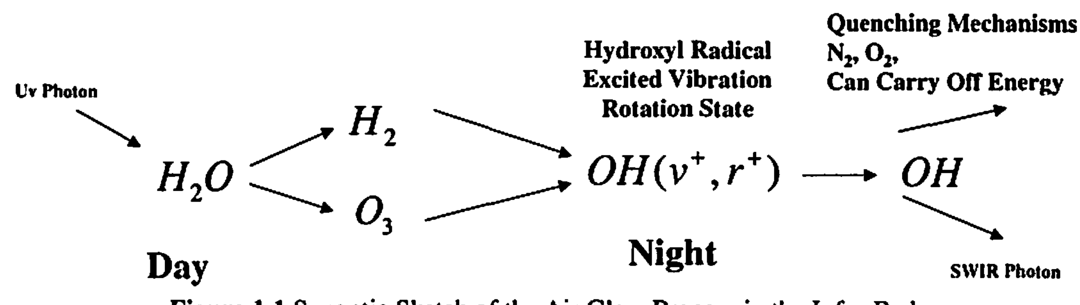


Figure 1.1 Synoptic Sketch of the Air Glow Process in the Infra-Red.

Figure 1.1 is a synoptic sketch of the air glow process for illumination in the SWIR band. Although the chemical reactions are very complicated, the overall effects can be summarized as follows. During the day, UV photons strike water molecules and initiate the production of hydrogen and ozone. At night, the hydrogen and ozone recombine and form the excited hydroxyl radicals with elevated vibration and rotational energy states. The molecules then transition to a lower energy state emitting a SWIR photon. The process can be quenched by other molecules, among them O_2 and N_2, which carry off the energy. Sources of night time illumination that can be used for imaging, shown in Figure 1.2, give the moon as the brightest source [1]. However, when the moon is not out, or is obscured by clouds, we see that, in the SWIR band, air glow provides a significant source much greater than thermal radiation.

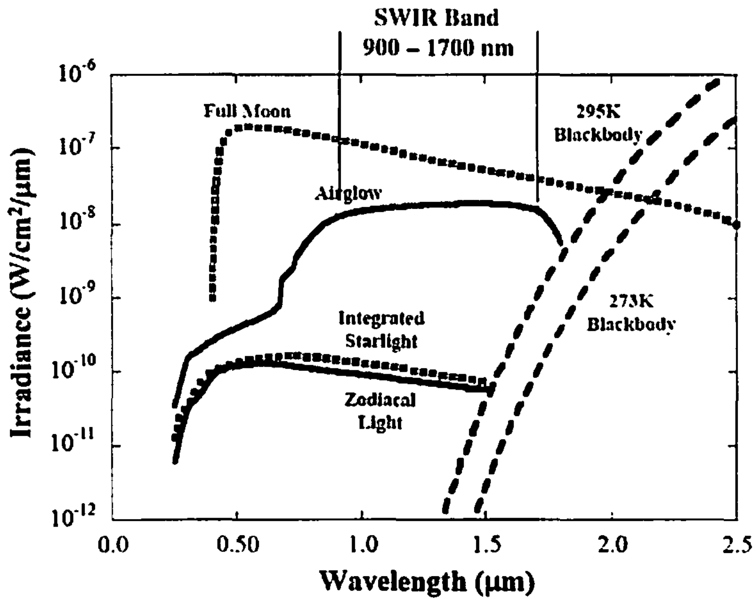


Figure 1.2 Night Time Illumination Sources

2.0 EXPERIMENTAL SETUP

The goal to record data on moonless nights at remote sites drove the design of the experimental setup to be rugged, simple to set up and break down, and fully automated. Critical features included controlling the gimbal position in a repeatable fashion, collecting simultaneous data from both cameras, recording Azimuth, Elevation, and Time with every camera image, and running for at least eight hours without operator intervention. A program script for the gimbal controller was developed to scan the sky continuously for approximately 12 hours. This program could be started from either the Hand Remote or from the PC. One complete scan consisted of forty five discrete positions as shown in Figure 3.2, and each position was held for 30 seconds. A full night of recording yielded around 20 scans. Data capture software was developed to 1) acquire SWIR images at 60 Hz, 2) read Gimbal Az/El positions from the controller, and 3) acquire low light visible images at about 9 per minute. A Block Diagram of the setup is shown in Figure 2.1. Figure 2.2 shows the Electronics Rack ready to pack and the system as deployed with the keyboard and monitor extended. The gimbal with both cameras mounted is shown in Figure 2.3. Also shown is a new all weather enclosure which has not yet been used.

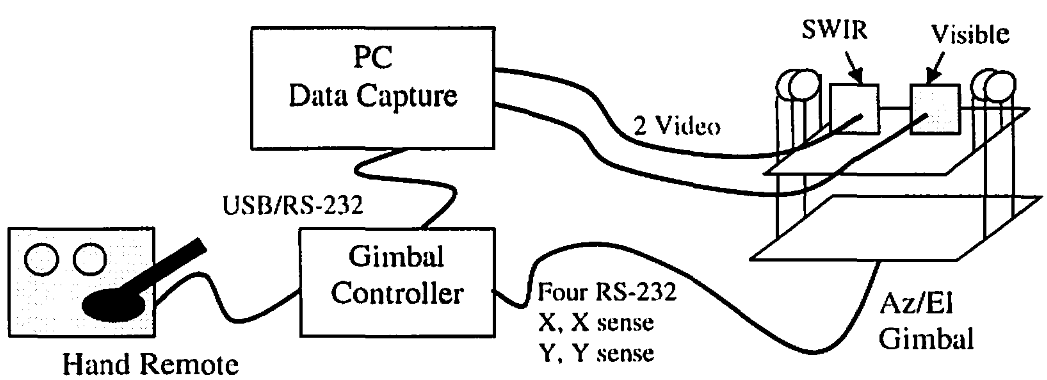


Figure 2.1 Block Diagram.

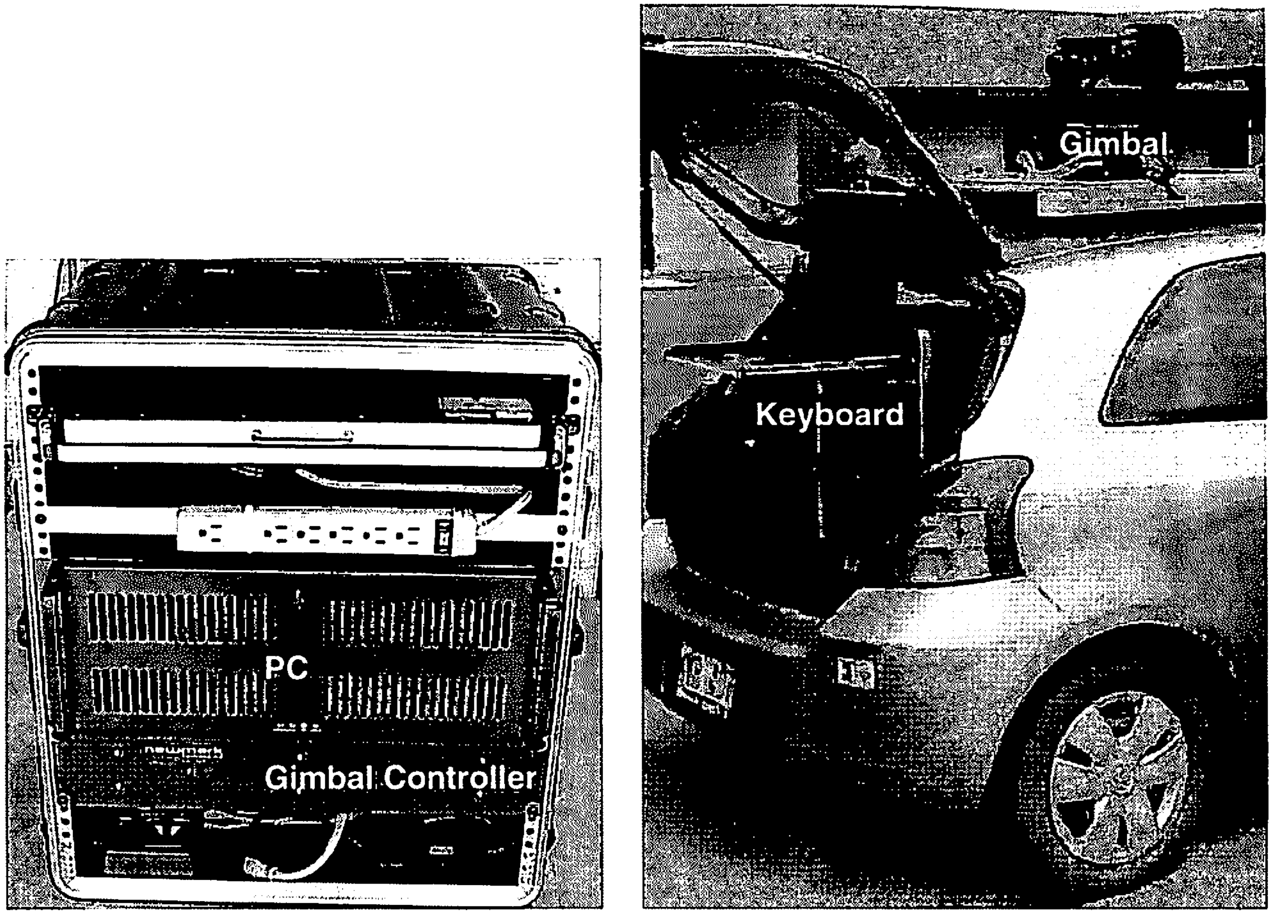


Figure 2.2 Electronics Rack and Field Deployment

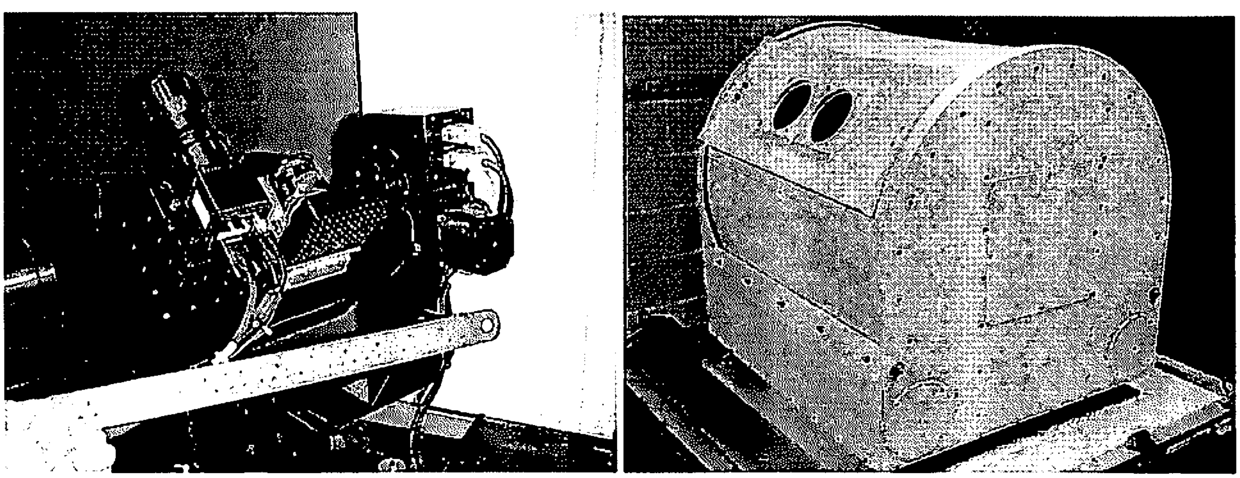


Figure 2.3 Newmark Gimbal with Cameras and Dome Enclosure

The SWIR camera used for the measurements was a Sensors Unlimited model 320KTX with 320x240x40 μm pixels. It has a quantum efficiency above 60 % from 900 nm to 1700 nm as shown in the curve in Figure 2.4. The effective read noise of the camera was measured to be about 50 equivalent detected photons per pixel.

SWIR image measurements shown in the subsequent sections were made using an F/1.4 50 mm focal length lens. With SWIR air glow irradiance levels, optics faster than F/2.5 are typically required for passive night glow imaging in order to concentrate enough light onto the detector array.

In order to make comparisons, a Meade low noise CCD visible camera with 1 second exposures, shown in Figure 2.5, was used in conjunction with the SWIR camera. Both cameras were co-mounted and aligned to infinity on the gimbal.

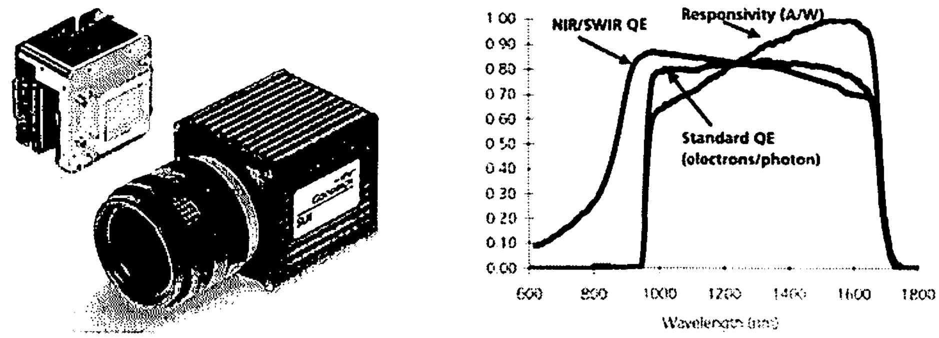


Figure 2.4 Sensors Unlimited SWIR Camera Used to Make SWIR Measurements of Air Glow.

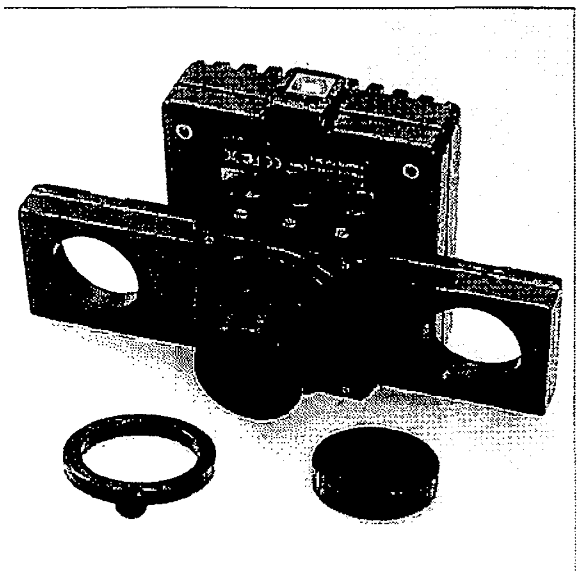
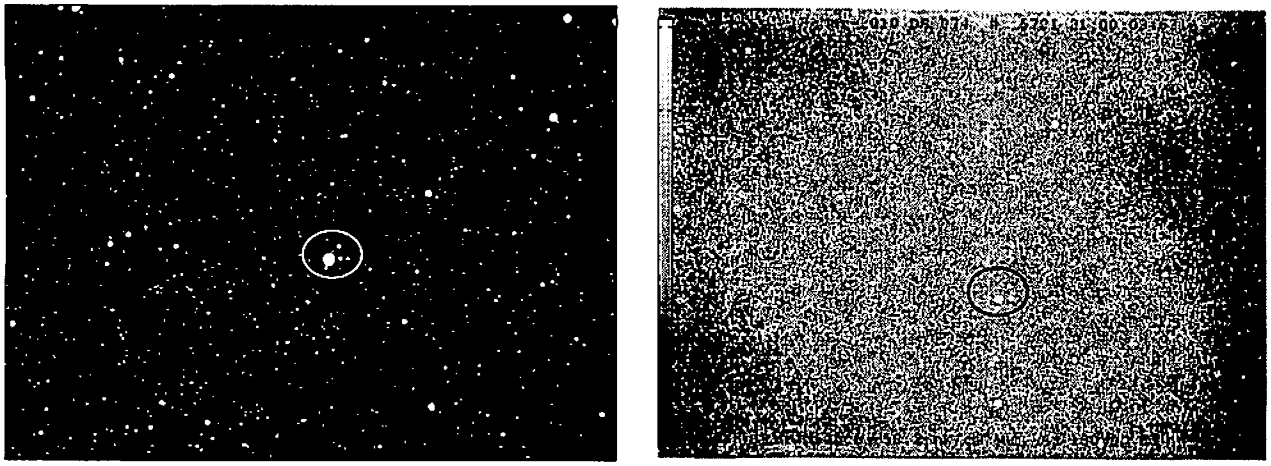


Figure 2.5 Meade DSI Pro II CCD Visible Camera

3.0 MEASUREMENTS

Image measurements were performed on the Hawaiian island of Kauai. The site was located on the west coast of the island with very little in the way of ambient light pollution. When the moon is not out, the only source of illumination is from the air glow.

The SWIR and visible cameras were co-mounted to an AZ,EL gimbal in order to obtain scans of the full sky hemisphere in an automated fashion. Figure 3.1 shows an air glow image and a visible image made near zenith. It can be seen from the visible camera data that there are no water vapor clouds. The air glow image gives a mean Irradiance of 58.2 nW/cm^2/um. Note that the contrast of the image has been enhanced so that "black" to "white" is 55 to 61 nW/cm^2/um. The gimbal moved through a series of positions arranged in concentric circles of constant Elevation, as shown in Figure 3.2. At each position 30 seconds of image data were collected.



Visible Camera SWIR Camera

Figure 3.1 Air Glow Measurements at 15 degrees off Zenith

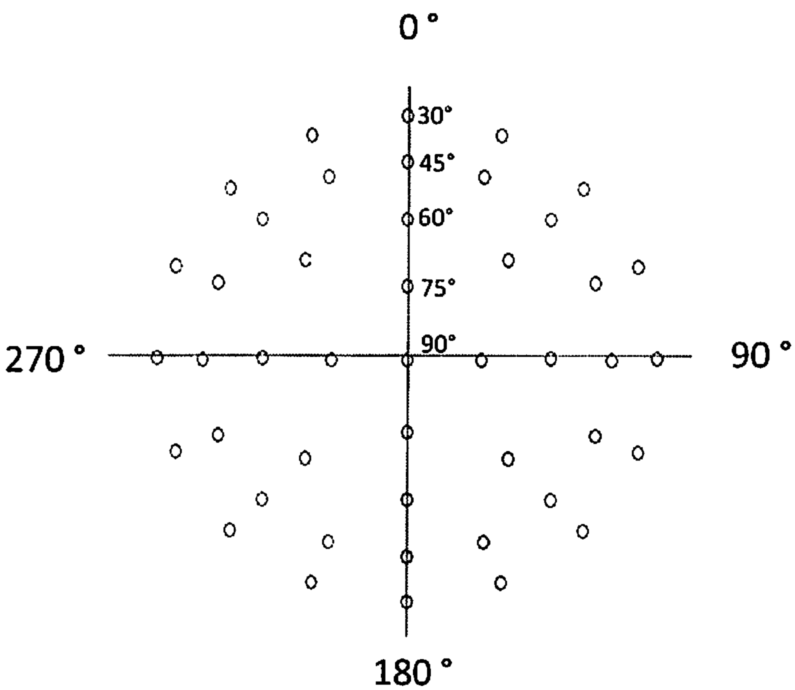


Figure 3.2 Scan Pattern for Recording Air Glow from the Full Sky

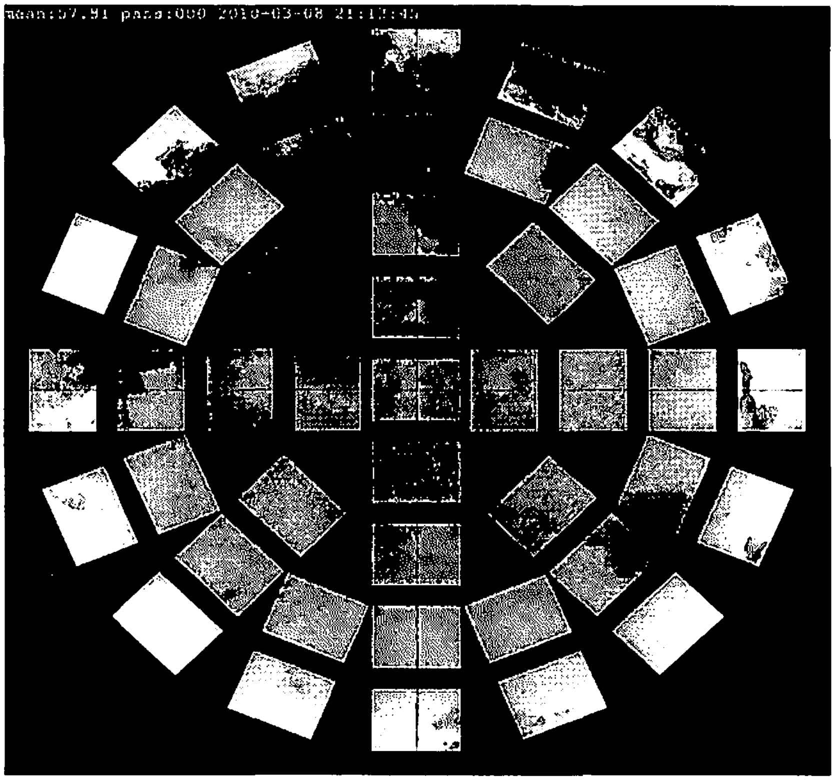
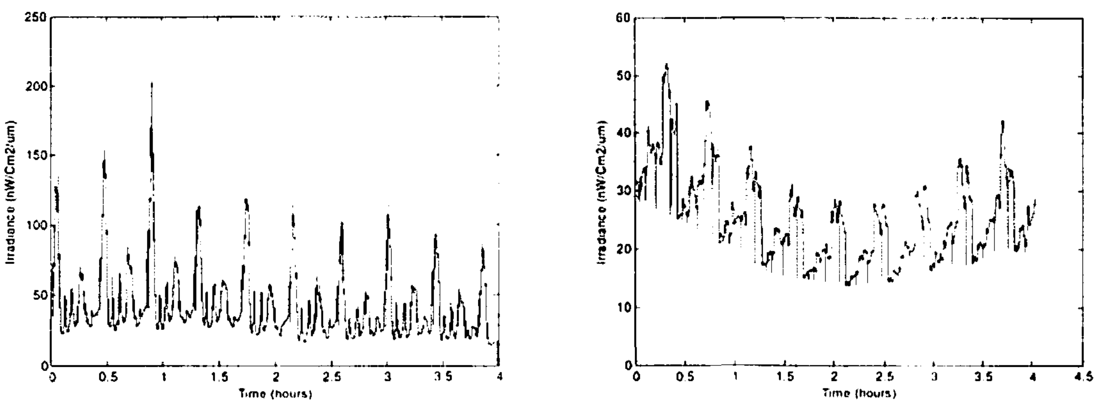


Figure 3.3 Full Sky Mosaic of Air Glow Images

Figure 3.3 shows a mosaic of images arranged to match where they were collected at each of the scan positions shown in Figure 3.2. The dark regions in the images are water clouds. Although it takes about 26 minutes to collect all 45 images, this collage presents a unique look at the air glow hemisphere. Note that the images taken near the horizon, especially on the outer ring, are brighter than those in the center. More SWIR energy is produced with decreasing elevation due to increasing line-of-sight thickness of the atmosphere, as modeled using the van Rhijn method [4].



a) Intensity Pattern Showing Little Long Term Variation   b) Intensity Pattern Showing Large Long Term Variation

Figure 3.4 Annular Scan Pattern for Recording Air Glow from the Full Sky

Figure 3.4 shows two time series plots for air glow data taken on two different nights in Kauai. Each point on the plot represents an average of the air glow intensity over each 60 Hz image frame. As the gimbal moved through it annular scan pattern, we can see periodic fluctuations in the plots, due to variations of the intensity with elevation angle. The peaks in the time series occur when the gimbal is pointed near the horizon, and the minima when the gimbal is pointed near zenith. The very bright peaks indicate lunar luminescence. Comparing Figures 3.4 a) and 3.4 b) we can see slowly varying fluctuations in the intensity over the course of the night. This is particularly noticeable in b) where we see dip in the long term intensity at about the 2 hour point. The mean of approximately 30 nW/cm^2/um is consistent with Figure 1.2.

4.0 CONCLUSIONS

Chemical luminescence from excited hydroxyl radicals in the upper atmosphere at about 80 km provides a natural illumination source for night time imaging in the SWIR band between 0.9 and 1.7 µm. A series of measurements were made of the air glow at different elevation and azimuth angles over many nights on the west coast of Kauai, Hawaii. Data reduction produced full sky image collages which showed an expected strong dependence on elevation. These measurements also showed both relatively flat and significant nightly fluctuations in the air glow irradiance. The long term mean irradiance levels measured were consistent with published levels. Figure 3.1 shows Figure 1.2 with mean data from Figure 3.4 drawn as a horizontal line.

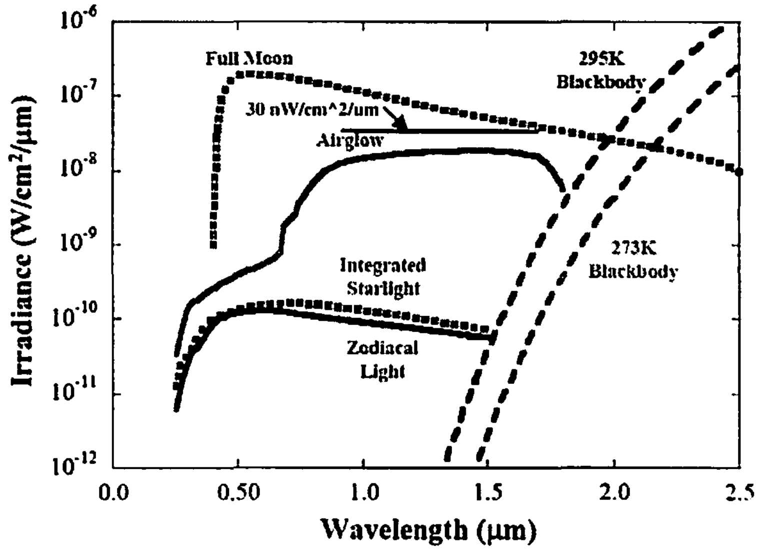


Figure 4.1 Night Time Illumination Sources with Air Glow Measurement Superimposed

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