The MAMBA Thermal All-Sky Camera

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ABSTRACT

MAMBA is an actively calibrated, thermal, all-sky camera designed to measure the precipitable water vapor (PWV) column in any arbitrary direction. This has applications in the calibration of remote sensing, astronomy, radio frequency transmissions, meteorology, and climatology. MAMBA produces an all-sky cloud map, day or night, which is useful in astronomy and SSA for telescope aiming. The system is based on a new optical design and an extensive set of atmospheric radiative transfer models.

1. INTRODUCTION

Oceanit is building a prototype thermal infrared all-sky camera, known as MAMBA. Thermal all-sky monitoring has proven extremely valuable at astronomical observatories, because it reveals cloud cover at night. A continuously updated cloud map allows observatories to continue operating in partly cloudy conditions, maximizing valuable operational up time. To date only a few such instruments have been built, notably the MAGNUM/Pan-STARRS cloud camera on Haleakala and RASICAM at Cerro Tololo. Both were one-off custom built units, and neither is currently operational. Oceanit plans to market MAMBA systems built to order starting in 2016, for the first time making thermal sky monitoring available as a commercial product.

MAMBA will be radiometrically calibrated, so in addition to imaging cloud cover, it will measure atmospheric thermal emission in clear-sky regions. Oceanit has developed a technique for using this information in conjunction with ground level weather data to infer mid and long wave infrared atmospheric transmittance between the ground and any arbitrary altitude.

In section 2 we discuss the optical design of MAMBA. In section 3 we describe its mechanical design and in section 4 we discuss our technique for inferring atmospheric transmittance.

2. OPTICAL DESIGN

MAMBA consists of two custom made convex mirrors (primary and secondary) and a COTS uncooled thermal camera (FLIR A655sc) with lens (see Fig 1). MAMBA has an equiresolution optical design, meaning that every pixel subtends the same solid angle on the sky. This is important for accurate radiometric calibration, because it eliminates geometric effects in relating sky brightness to pixel illumination. We achieved this by solving the differential equation laid out in [1].

The mathematical treatment of the mirror form assumes a perfect pinhole lens. Zemax modeling with the lens we will actually use showed 90% encircled energy within a two pixel radius pixels on the FLIR A655sc's 640x480 pixel focal plane (see Fig. 2). We performed tolerance analysis to guide the mechanical design.

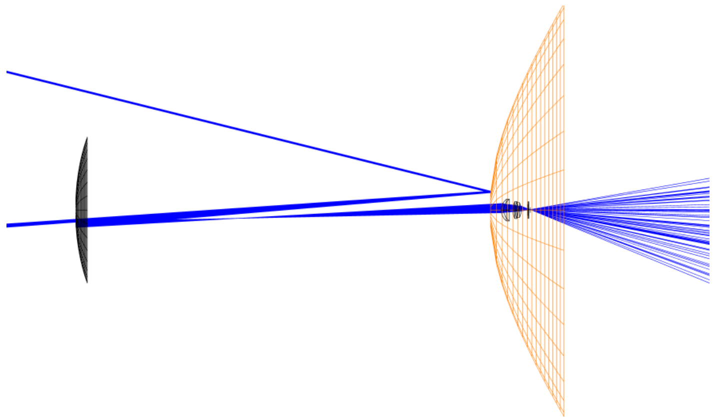

Fig 1. A Zemax wireframe rendering of the MAMBA optics, including the primary and secondary mirrors, the FLIR lens, and the focal plane. The blue lines are representative rays from a point source at infinity.

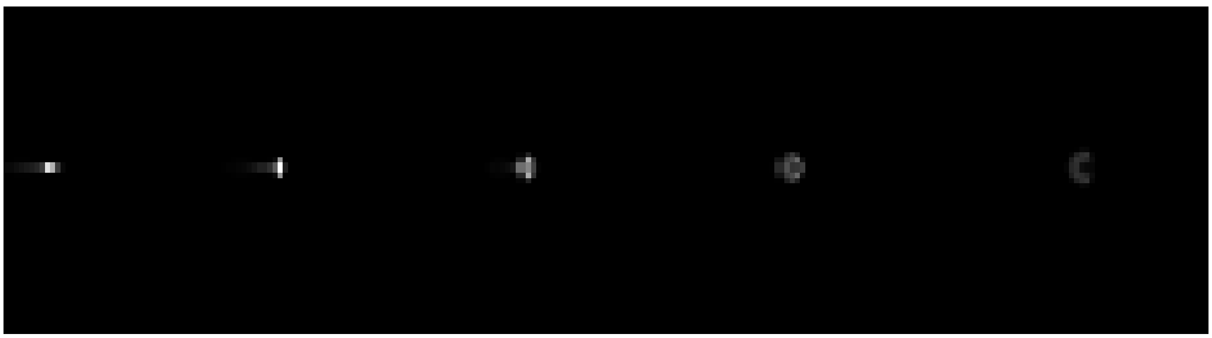

Fig. 2. Ray traced spot patterns on the MAMBA focal plane for point sources at a range of zenith angles. The distortions are typical of wide field optical designs and will not adversely affect the system, because we plan to spatially bin pixels to reduce noise. For all spots 90% of the spot energy falls within a 2 pixel radius.

3. MECHANICAL DESIGN

The mechanical design includes mirror supports and a mount for the thermal camera under the primary (see Fig 3). We used the results of our Zemax tolerance analysis to design a system capable of maintaining sufficient rigidity to maintain focus.

Fig 3. Solidworks renderings of the MAMBA mechanical design

4. INFERRING ATMOSPHERIC TRANSMITTANCE

The transmittance of the atmosphere in the mid and long wave infrared can vary over a large range because it depends strongly on the highly variable water vapor content of the atmosphere (see Fig. 4). This is a problem for a number of remote sensing applications and for the evaluation of infrared instruments.

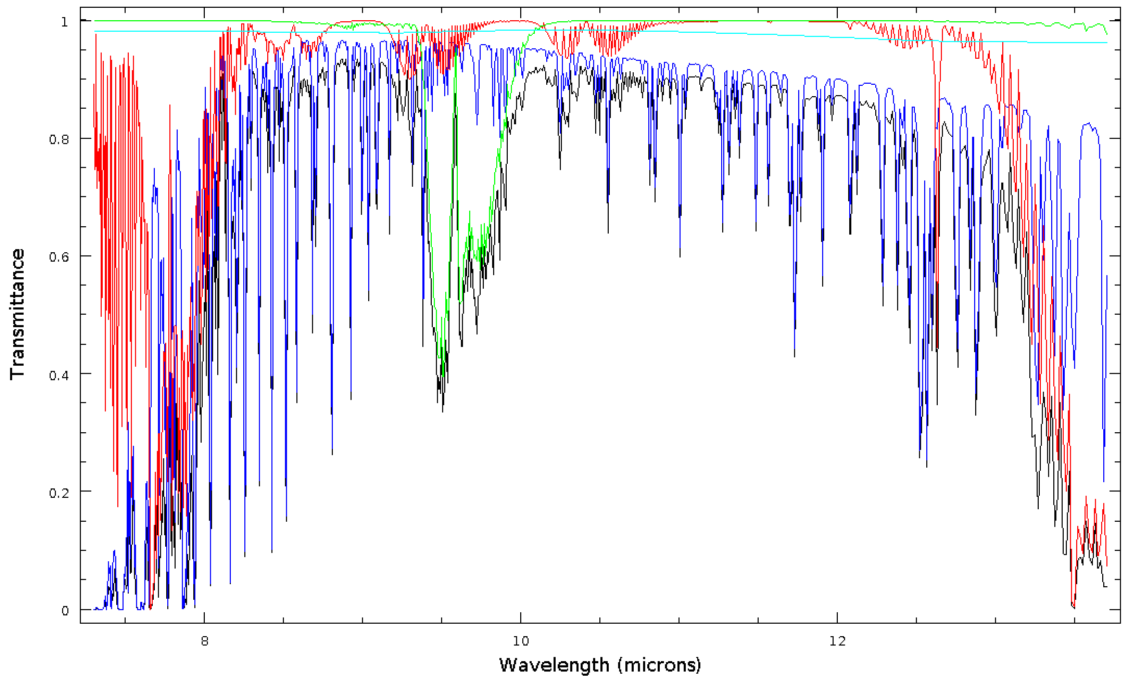

Fig. 4. Contributions to transmittance in the 10 µm atmospheric window as computed by MODTRAN for a representative atmosphere. The black curve represents the total transmittance, red is CO_2, green is O_3, blue is H_2O, and cyan is aerosol scattering. Water is the dominant absorber.

Oceanit has developed a novel technique for determining the IR atmospheric transmittance between the ground and arbitrary altitudes along arbitrary lines of sight using measurements only taken on the ground. Previous techniques for doing this all have shortcomings. Radiosonde balloons measure conditions along a single path at the time of the balloon flight. Continuous monitoring along arbitrary lines of sight is not possible. LIDAR systems are extremely expensive, and FTIR systems can only infer conditions along the line of sight to the Sun.

The key principle behind Oceanit's technique is that atmospheric absorbers are also atmospheric emitters. Investigators have previously shown that it is possible to infer the Precipitable Water Vapor (PWV) using low cost infrared thermometers to measure the thermal emission from the sky [2]. PWV is the total column density of water vapor between space and the ground. It therefore is strongly correlated with the IR transmittance to/from space.

Oceanit's innovation is to combine the atmospheric thermal emission with ground level weather data, which determines the low altitude opacity of air. When we do this we constrain both the asymptotic high altitude level of the transmittance vs. altitude curve and the slope at low altitude. Using historical Radiosonde data and MODTRAN simulations we showed that this was sufficient to constrain the transmittance at any altitude to within reasonable accuracy.

We calibrate the transmittance calculation by training a neural net on MODTRAN simulations of historical Radiosonde data. Our calculation therefore takes into account ground level conditions, conditions at altitude and historical weather patterns.

5. REFERENCES

1. Hicks, R.A., Millstone, M. & Daniilidiis, K., "Realizing an central projection with a mirror pair", APPLIED OPTICS, vol. 45, no. 28, 2006.
2. Mims, F. M., et. al., "Measuring Total Column Water Vapor by Pointing an Infrared Thermometer at the Sky", Bulletin of the American Meteorological Society, 92, 1331-1320, 2011.