

# Wide Field Telescope for Laser Illumination Avoidance and SSA Operations

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## ABSTRACT

We present an update on the further development of an all-sky, thermal infrared telescope for SSA observatory operations. Designed originally for the measurement of water vapor, we have extended the use of our MAMBA telescope to include cloud detection to determine viability of observations in any direction. In addition, it can be used for laser guide star operations by sensing aircraft and birds and preventing illumination of these objects. We also discuss its possible use for satellite tracking.

## 1. INSTRUMENT DESIGN AND THEORY



Fig. 1: MAMBA undergoing testing at night to measure atmospheric water vapor. Calibration black bodies are indicated by their power lights.

MAMBA [1], shown in Fig. 1, is an all-sky, imaging, thermal infrared telescope originally designed to measure precipitable water vapor at all angles into the sky. The optical design incorporates two custom-made mirrors: a convex, 0.7 m primary mirror as well as a concave secondary mirror, both made aluminum and coated with gold. These form an image of the entire sky (less a central obscuration cone of  $22^\circ$ ) located 20 cm above a FLIR A655sc thermal camera (uncooled) which uses a  $25^\circ$  lens. The MAMBA optical design is unusual in that each pixel is

equiangular (meaning each pixel subtends the same solid angle) across the entire field of view. Each pixel is  $0.5^\circ$  on a side, with a solid angle of  $7.6 \mu\text{sr}$ .

The MAMBA instrument has evolved over three iterations (shown in Fig. 2). Notable enhancements in subsequent generations include replacing the aluminum secondary struts with carbon fiber ones, and improving the mechanics of the sun blocking strip that floats just above the primary. The sun blocker updates its position continuously in order to prevent the camera from imaging the solar disc directly.

MAMBA directly measures the sky radiance in the thermal infrared, which is subsequently used with thousands of MODTRAN [2] atmospheric simulations as well as a neural net to infer the precipitable water vapor (PWV) to arbitrary altitudes – but most often to space. Water vapor is the dominant absorbing chemical species in the thermal infrared (IR). Local weather data and radiosonde data are used whenever available to improve accuracy.

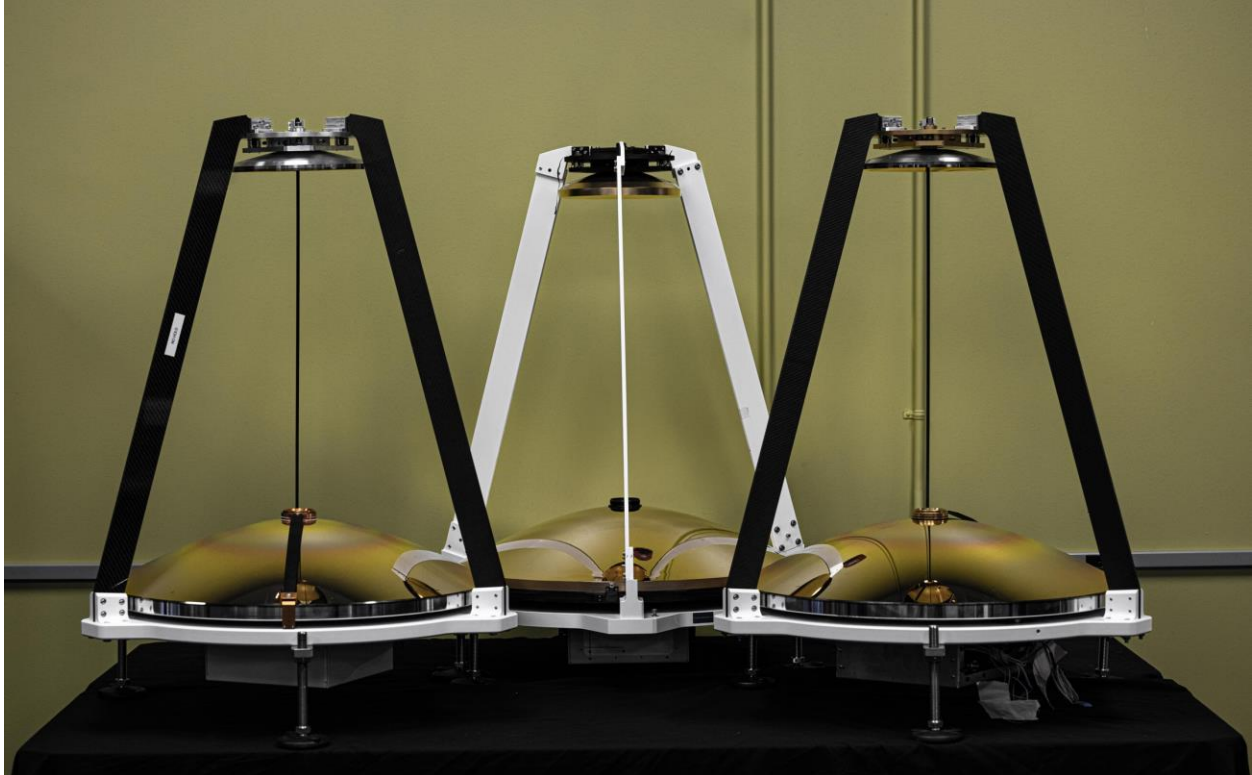


Fig. 2: Three generations of MAMBA have already been constructed. The first model is at center, the second can be seen on the left (note carbon fiber vanes), and the third generation model is on the right.

## 2. AIRCRAFT TRACKING AND CLOUDS

We are currently working on using the telescope to track aircraft for AFRL in order to prevent accidental illumination with artificial guide star adaptive optics lasers. Various algorithms for aircraft detection are currently being tested. Some initial results can be seen in Fig. 3, where all aircraft above a  $70^\circ$  zenith angle are successfully detected using a simple thresholding algorithm – lower zenith angles than this will not be relevant due to the fact that the telescope will not be able to point that low in the sky. In the future we will be augmenting these algorithms with neural net-based tracking. We expect our final software to make use of multiple techniques.

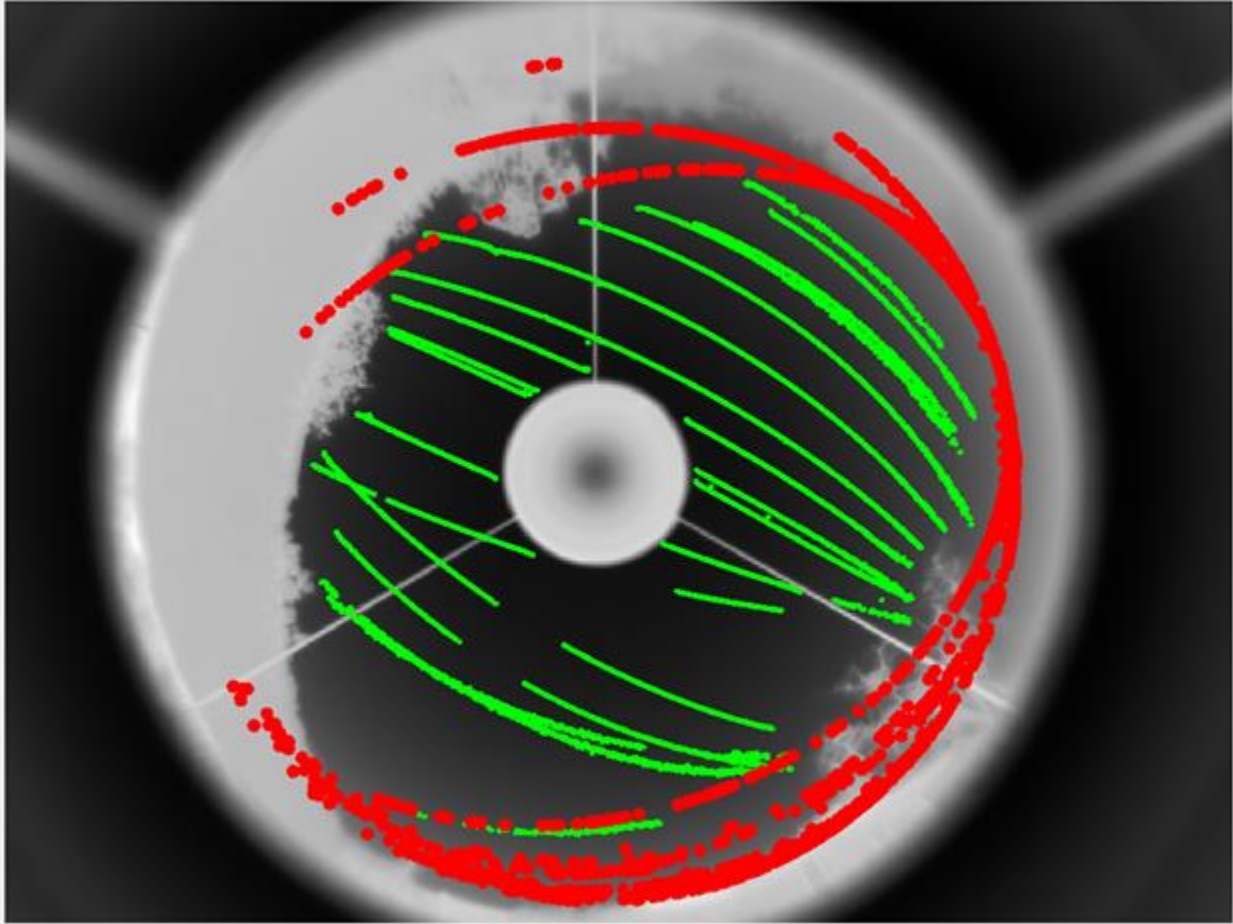


Fig. 3: Aircraft trajectories detected by our processing software. All aircraft above a  $70^\circ$  zenith angle (shown as green tracks) are successfully detected.

Another important data product is a constantly updated map of cloud cover (see Fig. 4), which enables the directing telescopes to observe through “holes” in the clouds. Clouds are visible in the infrared before being evident in visible imaging, allowing us to predict cloud formation. They are easily detected and need to be masked in order to detect other moving objects. Thermal radiance is also used to estimate transmission in other wavelengths.

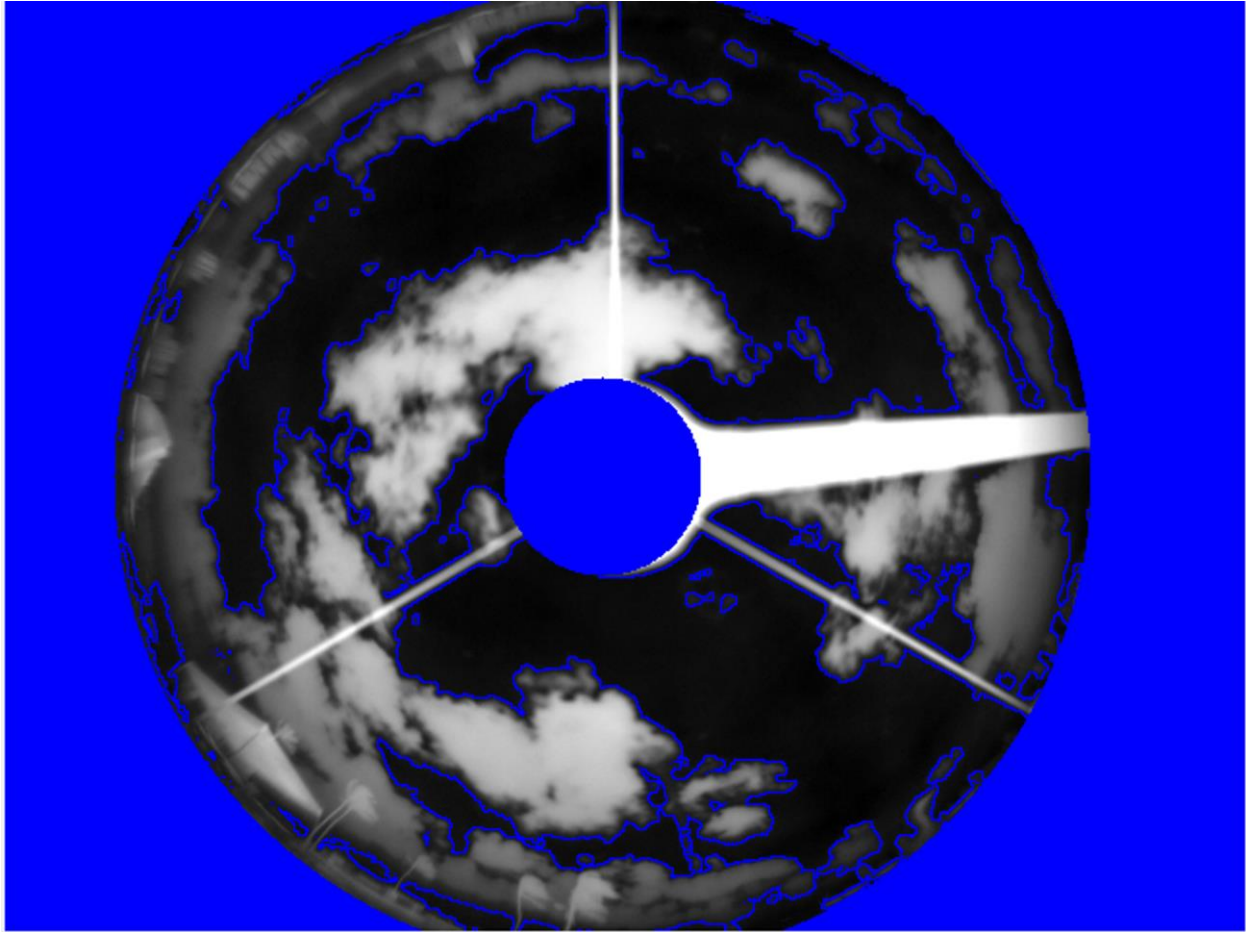


Fig. 4: In this frame, taken at a site with significant obscuration of the sky, clouds and fixed obstacles are masked in blue.

### 3. COMPLICATIONS: INSECTS AND BIRDS

Most of the detected tracks in our testing have not in fact turned out to be aircraft, but birds and insects. Fig. 5 shows a plot of aircraft and bird tracks detected by our system. Insects dominate the tracks, and are not shown since their tracks would otherwise cover the entire plot. We have found that by measuring the “wiggleness” of the tracks and subsequently applying time-based low-pass and high-pass filters, we can successfully excise the insects and birds from our candidate object list.

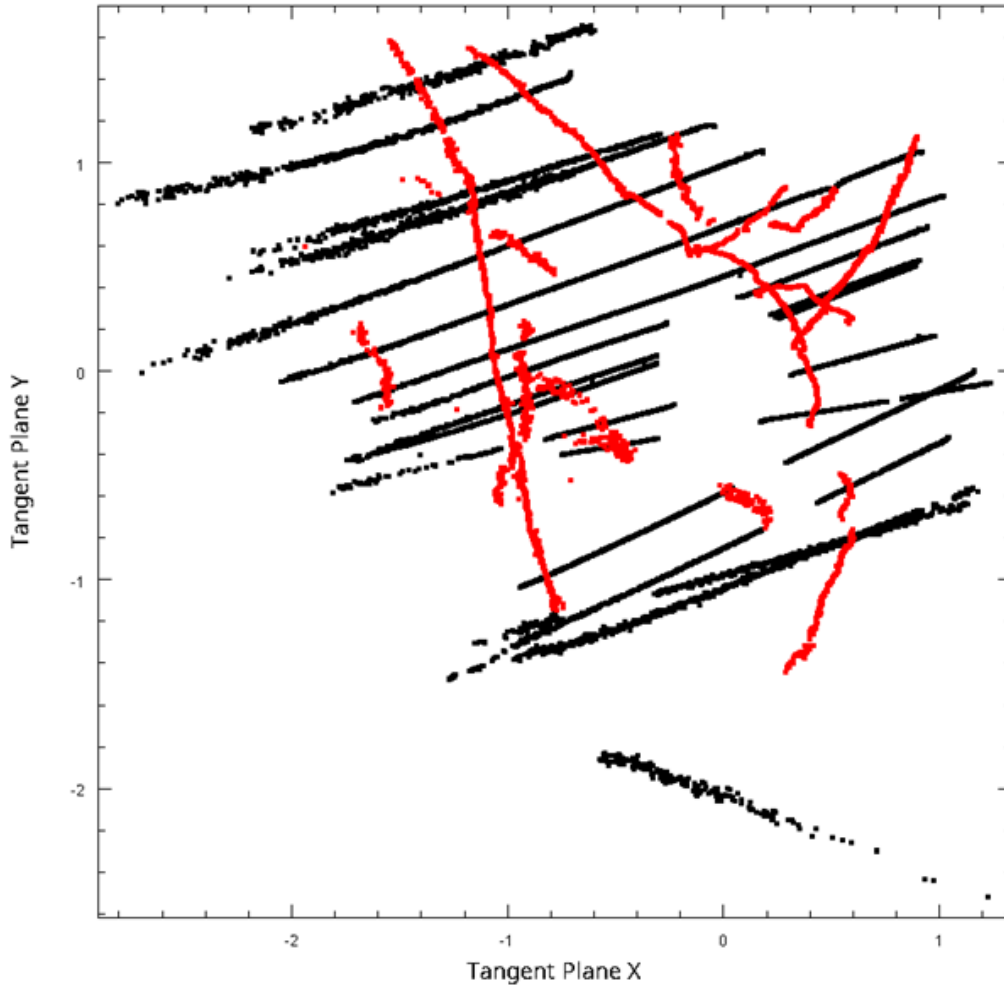


Fig. 5: In a tangent plane projection, aircraft tracks are shown in black, and bird tracks in red.

#### 4. NEXT STEPS

We continue to gather more data in order to train our neural networks and refine our successive track selection algorithms. We will also be improving the ruggedization of the system in preparation for permanent installation at an observatory site.

After our algorithms are able to excise all of the noise from airborne objects, we will experiment with detecting satellites directly.

#### 5. ACKNOWLEDGEMENTS

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#### 6. REFERENCES

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- [2] A. Berk, P. Conforti, R. Kennett, T. Perkins, F. Hawes, and J. van den Bosch. “MODTRAN6: a major upgrade of the MODTRAN radiative transfer code”. *Proc. SPIE 9088: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XX*, 90880H, 2014.