

# Mass-Dimm Setup at Palomar

## 1. Introduction

Palomar Observatory currently hosts two robotic MASS-DIMM systems. The first is a version of the TMT site-testing equipment (T5) which has been operating on the roof of the power-house building at Palomar since May 2005 [1,2]. Although T5 is destined to go to another site, this system has demonstrated the utility of having access to detailed turbulence profiles, especially for comparison with our Adaptive Optics measurements and development of our Laser Guide Star Adaptive Optics program [3].

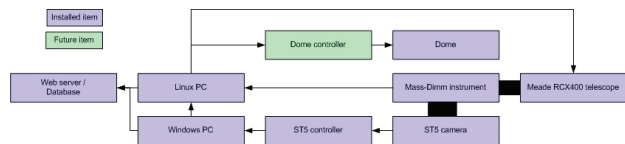
The new P18 system described here was installed in an existing (18-inch) dome in mid-2006. It is based on a combined MASS-DIMM unit (MD-18) built at Tololo and fed by a 12 inch Meade RCX-400 telescope. This system monitors Polaris and delivers real-time data every clear night [4].

## 2. Hardware

The MASS-DIMM instrument is a combination of a DIMM and a MASS sensor. MASS (MultiAperture Scintillation Sensor) measures four scintillation indices in a small central, circular aperture and 3 concentric annular apertures. From these are derived 6 differential scintillation indices for all possible pairs. Using these values it is possible to calculate some integral characteristics of the atmospheric turbulence and restore a low-resolution vertical turbulence profile with 5 to 6 layers. Note that the MASS does not sense turbulence in the boundary layer (lower 500 m above ground) [5].

DIMM (Differential Image Motion Monitor) measures fluctuations of the angular distance between two images produced by two circular apertures about 10 cm in diameter separated by about 20 cm. The DIMM measures both low and high altitude turbulence along the complete line-of-sight, and therefore supplements the MASS unit well.

The DIMM system uses a SBIG ST5 camera with software running on Windows, while the MASS system uses custom electronics and software running on Linux. We therefore use two Little-PCs [6] to control the system. Finally a remote computer grabs the seeing data and serves the data for the user community on a website [4]. A block diagram of the hardware can be seen in the figure below.

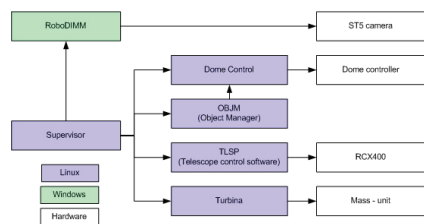


## 3. Software

The software consists of the following programs:

- RoboDIMMnet (Windows) - measures the DIMM seeing using the ST5 camera
- Turbina (Linux) - controls the MASS instrument and computes the seeing profile
- OBJM (Linux) - selects the optimal star to monitor from a small database (currently only Polaris is in the P18-MD OBJM database)
- TLSP (Linux) - telescope control software
- Supervisor (Linux) - starts and stops observations, and controls the measurement cycle

A block diagram of the software can be seen below:



## 4. Calibration

As described by Tokovinin [7], it is necessary to carefully tilt and align the MASS-DIMM unit on the telescope to ensure the projected apertures at the front window telescope surface are not obscured by the telescope outer diameter, or its central obstruction. The pupil magnification and pixel scale can be calibrated by measuring the apparent diameter of each of the MASS diameters and the size and separation between the two DIMM apertures, and comparing them with the physical sizes of these apertures ([7], figure 3). This can be done by shining a light through each aperture, and drawing the projected images on a piece of paper held against the front window of the telescope. The back projected images should be sharp, otherwise the Fabry lens needs to be adjusted.

The projected DIMM aperture sizes for our system were measured to be 9.0 cm, and their separation is 21 cm. The CCD pixel size was measured to be 0.834 arcsec/pixel. The value described in [7] of 0.85 arcsec/pixel was used.

For the MASS instrument, the magnification and focal length must be set. These depend on the optical system, i.e. telescope. The system magnification can be calculated based on the measured value of the back project MASS annulus diameters and the physical size of the segmentator diameters, which is supplied in the device dependent configuration file.

The two outer MASS apertures were measured to 9.0 and 6.1 cm. Calculating the magnification using the measured values for the segmentator, gives a magnification of 16.4 for the outer diameter, and slightly smaller for the second. Diameters of the two inner segments were not used, as the accuracy of the measurement was too poor. Thus we use a magnification value of 16.4, which happens to be the same value used in [7].

Finally the noise of the photon counters was measured and the averaged value over 10 test runs was entered into the Turbina configuration file.

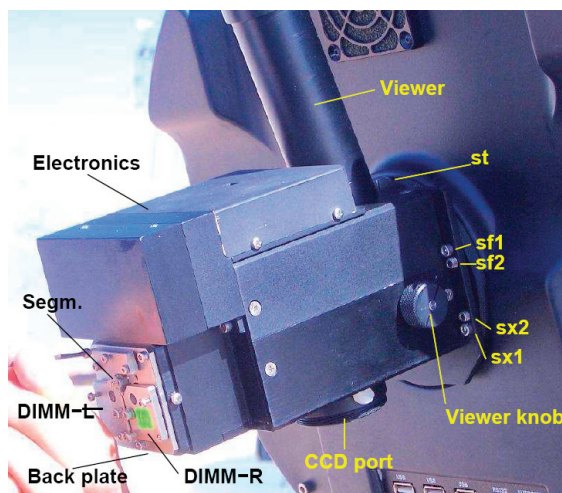
## 5. Dataprocessing

The DIMM instrument measures the summed Free + Boundary seeing. The data is stored in a file on the local DIMM computer. A new file is generated for each night. The MASS instrument estimates the seeing at different heights, namely 0.5, 1, 2, 4, 8, and 16 km above ground level. The turbulence in the lower 0.5 km of the atmosphere, the so-called Boundary Layer, is not detected by the MASS instrument. Both the MASS and DIMM data are measured and recorded approximately once every 90 seconds, but they are not synchronized and the interval between two measurements is not constant for either instrument.

By combining the data from the DIMM and MASS instruments, it is possible to calculate the boundary layer seeing. One problem is that the DIMM and MASS measurements are not simultaneous in time. This is addressed by linear interpolation. Finally the Fried parameter, isoplanatic angle, and lateral coherence scale parameter is calculated and presented on plots. The algorithms for the data processing is described in detail in the paper.

## 6. Webserver

The webserver retrieves the ASCII data files from the DIMM and MASS computers. The relevant data is extracted, and dataprocessing is performed. These data are used to generate plots using GNUplot [8]. The server retrieves data from both the MASS-DIMM instrument described here, and the TMT T5 MASS-DIMM. Our scripts are written in Perl and run once per minute. The necessary webpages are dynamically updated whenever new data is available. The main page shows data from the last operating night for both systems. Another page shows graphs from the past 3 weeks and a third page provides links to all ASCII data and plots, which can be used by the observers for further processing. The data format of the text files is described on the website.

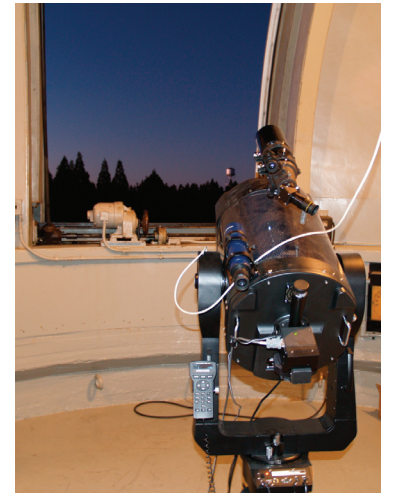
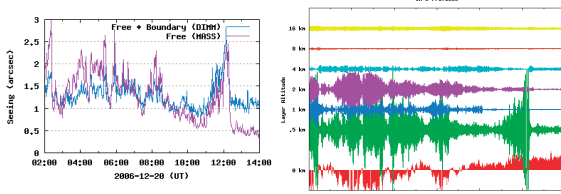


The MASS-DIMM instrument mounted on a RCX400 telescope [7]

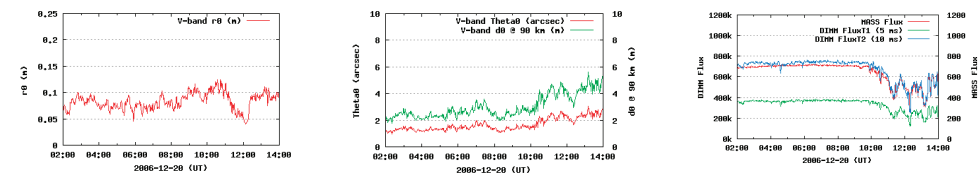
## 7. Results

### Turbulence Profiles and Parameters

A number of plots are generated and shown on the website. For the turbulence parameters, a reference wavelength of 500 nm is used, but for convenience is referred to on the plots as "V band". The top left plot shows the seeing measured by the DIMM and MASS instruments. Since the DIMM measures the summed Free + Boundary seeing and the MASS only measures the Free seeing, the value shown for the MASS instrument should not exceed the value shown by the DIMM instrument. However, lower level saturation effects may cause the free-atmosphere estimates to exceed the measured DIMM seeing.



The MASS-DIMM system installed in the P18 dome



The top right plot shows the height resolved MASS measurements (for each of the nominal 0.5, 1, 2, 4, 8, and 16 km layers). In addition the ground layer profile (0 km) is calculated during the data processing by combining DIMM and MASS data. When the free-atmosphere seeing exceeds the DIMM seeing, the lowest layer in this figure is displayed as a negative value.

The Fried parameter is shown in the lower left plot. Large values of  $r_0$  indicate that the wavefront is smooth, resulting in good image quality.

The lower middle plot shows  $\theta_0$  and  $d_0$ . AO systems should deliver uniform image quality over fields of size  $\theta_0$ , centred on the guide star, so large values of  $\theta_0$  indicate good image quality over large fields of view. For a laser guide star adaptive optics system, the wavefront phase differences are small near the center of the aperture, but grow as one moves out in the aperture plane. For apertures smaller than  $d_0$ , an AO system can deliver good image quality. For larger apertures, the differential phase aberrations become large at the outer edge of the aperture, resulting in little improvement in the image quality. In this sense,  $d_0$  sets the effective size of the correctable aperture for a single laser guide star adaptive optics system. Large values of  $d_0$  result in good image quality. The value of  $d_0$  depends on the height of the laser beacon, and for these calculations a height of 90 km is assumed.

Note that the Fried parameter,  $r_0$ , the isoplanatic angle  $\theta_0$  and the focal anisoplanatism parameter  $d_0$  all depend on wavelength to the 6/5th power. The results presented in these plots are for 500 nm wavelengths. Longer observing wavelengths yield better image quality.

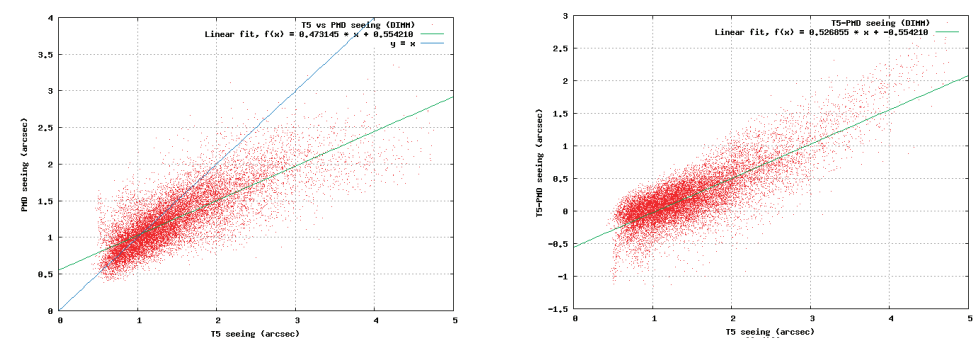
The final plot (lower right) shows the atmospheric transparency computed from the raw counts measured using the DIMM and MASS instruments. The DIMM instrument captures images with alternating exposure times of 5 ms and 10 ms. Therefore two flux values are shown for the DIMM instrument. The flux estimate for the 10 ms DIMM image should be twice as high as the 5 ms DIMM image. A flux estimate from the MASS instrument is computed by summing the raw counts of the four channels. All three values should correlate, but have different magnitudes. Since the PMD is staring at Polaris, the airmass correction is constant.

### T5/P18-MD Comparison

Turbulence profile measurements from the P18-MD unit may be compared to those from the T5 unit. Since these systems operate using different telescopes, this cross-comparison provides a consistency check, but since they are sited some 300 m apart local differences can occur. T5 sits on a concrete roof, is open to the atmosphere at night, but can suffer from local ground cooling effects in the evening. P18 is sited inside a dome with more wind protection. It is also important to note that T5 is tracking different stars during the night, whereas the P18-MD tracks Polaris all the time. This, and the difference in location and dome, will cause some difference in the measurements. So far we have only compared the DIMM dataset.

Since the two instruments sample independently it is necessary to somehow align the two datasets in time. The method for this is described in the paper.

The data has been plotted in the following two figures. To the left T5 vs P18-MD DIMM seeing is plotted, and to the right the difference (T5 minus P18-MD) is plotted using the T5 data points as reference. The blue line shows the 1-to-1 relation, and the green line shows a linear fit. These plots show that the P18-MD works up to a seeing of about 2.5 arcsec, above which the P18-MD does not capture the increased seeing. During operation we have also observed that the instrument when performing the spiral search during high seeing, has not recognized Polaris and skipped past it. This also explains why we get so few data points for the higher seeing values in the comparison. Fortunately for image quality assessment the data obtained in better seeing conditions is of highest interest.



## 8. Implementation Status

The P18-MD unit was installed in September 2006. It has since been running every clear night, however it currently has some trouble finding Polaris during high seeing conditions. During normal operation, when the star has first been found tracking the star works really well, it is only lost when a cloud covers a star.

Sometimes the MASS instrument is overshooting the DIMM instrument. A new version of the Turbina software with improved data processing has been developed, but we have not yet installed it. Likewise the dome is still opened and closed manually, however an automatic system is being installed.

## 9. Conclusions and Future Work

The new DIMM instrument seems to have a problem during high turbulence, but it correlates well at seeing below about 2.5 arcsec. Fortunately for image quality assessment the data obtained in better seeing conditions is of highest interest. We are continuing to operate and experiment with the system to explore its predictive capabilities for: (i) Anisoplanatism comparison with LGS-AO observations, (ii) PSF fitting for narrow and wide field applications, (iii) input to GLAO measurements and (iv) site characterization.

## References

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- <http://www.gnuplot.info/>

# 1st Symposium on Seeing

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