New instruments to see the "seeing"

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NOAO-NSO Newsletter, Issue 77, March 2004, pp. 32-34
This version is slightly different from the published article.

Ground-based astronomy is seriously affected by "seeing" – image degradation in the terrestrial atmosphere. Recognizing this, major observatories are equipped with seeing monitors (called DIMMs for Differential Image Motion Monitors), while site surveys for new telescopes (e.g. the ongoing survey for TMT – Thirty Meter Telescope) consider seeing to be one of the major selection criteria. Still, knowing just seeing is not enough. We need to know where it comes from, that is to measure the vertical distribution of turbulence in the atmosphere and its speed. This information is vital for designing adaptive optics and for understanding the mechanisms of the seeing itself.

Here comes MASS – a small instrument to measure vertical turbulence profile. Unlike previous techniques, it is simple and inexpensive, destined to work continuously as a turbulence monitor at existing and new sites. MASS is based on a statistical analysis of stellar scintillations in four concentric-ring apertures. This novel approach was proposed in 1998 and tested the same year at Mt. Maidanak in Uzbekistan. The first MASS instrument came into operation in 2002 at Cerro Tololo (Fig. 1). It was built by a team at the Sternberg Astronomical institute (Moscow) led by Victor Kornilov under AURA contract. The control software provides on-line data reduction, so one can watch the turbulence evolution on a computer screen in real time.

What do we learn from MASS?

The vertical resolution of MASS is low, only about 1/2 of altitude. The whole atmosphere is subdivided into 6 thick "slabs", and turbulence intensity in each layer is measured. Yet, this information is a significant addition to plain seeing data and gives new insights.

During the first year of MASS operation at Cerro Tololo we learned few new things about seeing. It is true that, typically, the first kilometer above summit gives most of turbulence. However, this layer cannot be *very* strong. When the seeing is really bad (say, above 1.5 arc-seconds), it surely comes from higher layers, and hence is equally bad on all neighboring mountains. On the other hand, periods when the whole upper atmosphere is very calm and gives a seeing of only 0.2-0.3 arc-seconds are not uncommon. During these periods, the seeing is entirely dependent on the ground-layer turbulence, hence subtle differences between mountains, locations on the same mountain, and even hight of telescope dome become very important. When everything is good, images as small as 0.3 arc-seconds (in the visible) are obtained, as demonstrated e.g. at Magellan and VLT.

Good seeing is rare and fragile because it comes by a coincidence of several independent conditions. We can make it more frequent by compensating the ground-layer turbulence with a special kind of adaptive optics. Such instrument is being designed for the 4.2-m SOAR telescope. Data obtained with MASS at Cerro Pachón in 2003 were very useful for statistical prediction of the resolution gain

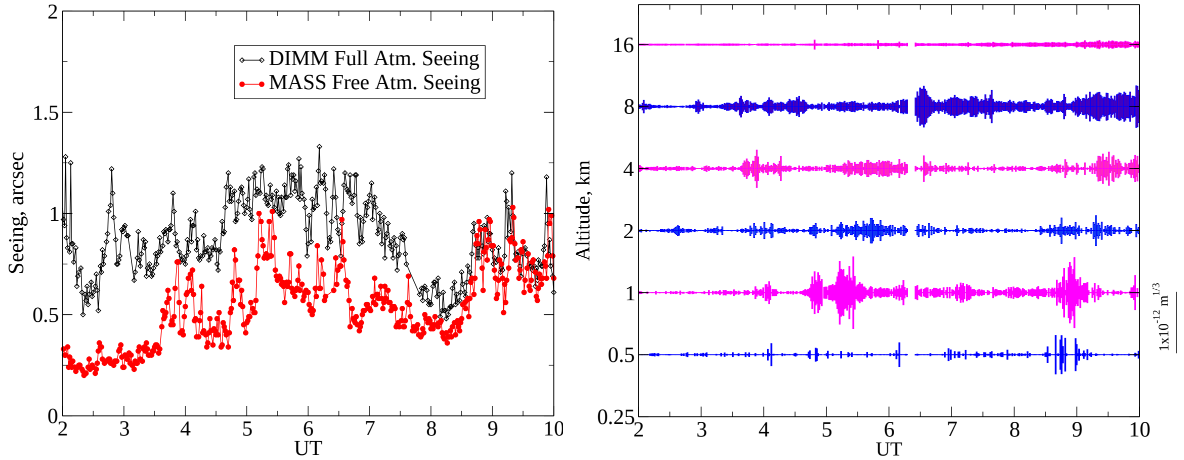

Figure 1: Evolution of seeing (left) and turbulence profile (right) on the night of July 14/15 2002 at Cerro Tololo. During the first half of the night the free atmosphere is calm and the seeing is completely dominated by the ground layer. This layer weakens by 8h UT, but the seeing is soon degrared again by turbulent bursts in high layers.

expected from this instrument. It turns out that the gain is indeed significant (of the order of 2) most of the time.

Combining MASS with DIMM

Ground-layer turbulence does not produce any scintillation, it is not sensed by MASS. On the other hand, DIMM senses the whole atmosphere. Turbulence intensity in the ground layer can be found by combining MASS and DIMM data: the two instruments should always work together!

Yet another reason for this "marriage" is that DIMM is wasteful, using only two portions of its telescope mirror and throwing away the rest. Indeed, the same telescope can and should feed both instruments. Facing this challenge, we developed a combined MASS-DIMM instrument. In its interior, an image of the telescope pupil is formed and segmented: two apertures are sent to the DIMM channel, whereas four concentric apertures are cut out to feed the MASS detectors.

MASS-DIMM is designed to work with small portable telescopes, such as Meade LX-200 (Fig. 2). Hence, the instrument itself is very compact and weights only 1.2 kg. The optics is also tiny: the diameters of the 4 MASS mirrors range from 1 mm to 5.5 mm. The instrument is meant to work in harsh environment: it is sealed from dust, there are no moving parts inside (apart from manually activated viewer mirror). MASS electronics is a real masterpiece: 4 miniature Hamamatsu photomultipliers are packaged together with high-voltage supply, photon counters and microprocessors in a single modular unit. A 4-wire RS-485 cable connects to a PC computer and only a +12V power is needed to make it all work. Despite small size, this electronics designed by V. Kornilov makes no compromise on performance: the dead time of the photon counters is only 12 ns – among the fastest in the world.

Nine MASS-DIMM instruments were fabricated in October 2004. The electronics, optics, and software were prepared by Kornilolv's team in Moscow while mechanical fabrication, integration, and testing were done in La Serena.

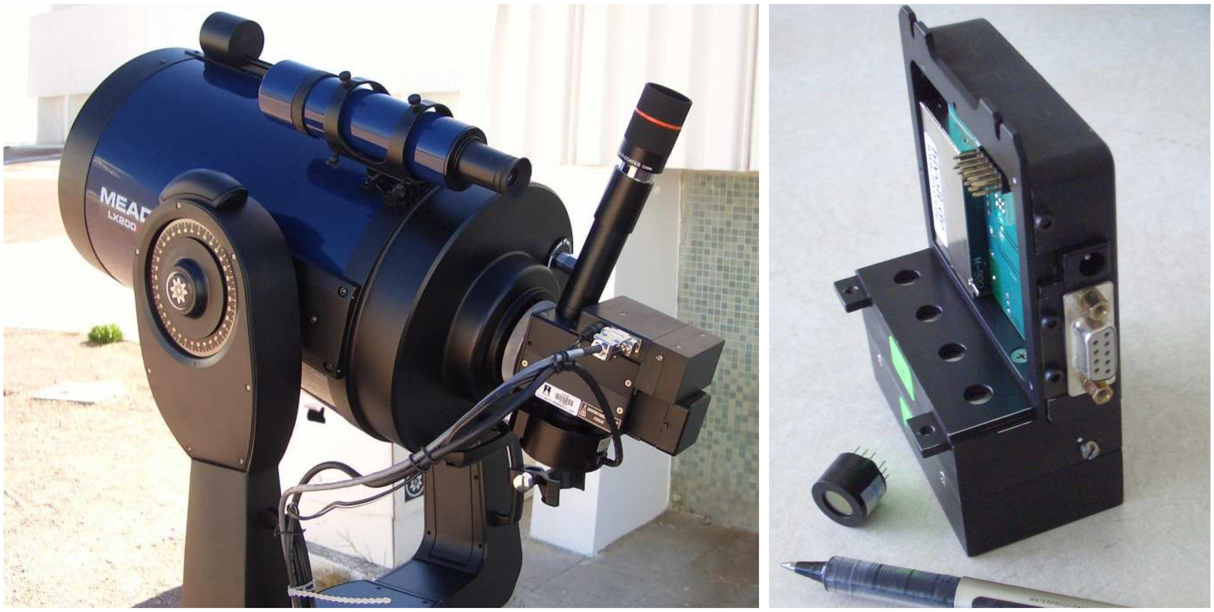

Figure 2: MASS-DIMM installed at the Meade LX200 telescope (left) and its electronics module (right) containing 4 tiny photomultipliers (one shown apart), photon-counting circuits and microprocessors.

Are we ready to get data?

MASS-DIMMs are intended to replace regular DIMMs as site monitors at Cerro Tololo, Cerro Pachón and Las Campanas. Other units will be used in the TMT site testing campaign: the first one is already installed, other will go to potentially interesting sites like Mauna Kea or San Pedro Martir in Mexico. Finally, one unit was sent to an Antarctic site, Dome C, in collaboration with a team from the New South Wales University (Sydney).

Operating multiple instruments in robotic mode is a new challenge. To complicate the things, at least 3 different telescope systems are being used with MASS-DIMMs, with three different versions of the control software. Furthermore, the CCD detectors of DIMM are operated under Windows OS, whereas other components including MASS are Linux-driven. Consequently, the effort of setting up and operating MASS-DIMMs is split between different teams, the CTIO being responsible only for the Meade-based version.

With MASS-DIMM instruments coming into operation one by one, managing the data flow becomes a task in itself. As a first step, the MASS data from 2002 have been made accessible on the WEB. Now we have to develop a full-fledged database that will facilitate the control of data quality and will make the data available for both immediate use and in-depth analysis.

Further information:

MASS web site: *http://www.ctio.noao.edu/ atokovin/profiler/*
MASS database: *http://mass.ctio.noao*
AURA site-testing: *http://www.ctio.noao.edu/sitetests/*