DIMM 2-pager

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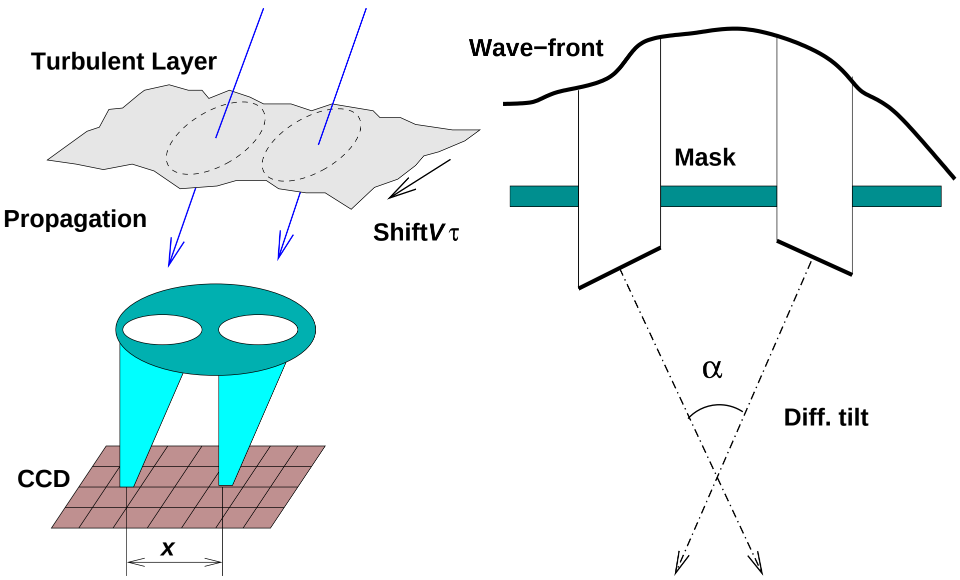

Figure 1: DIMM principle. The scheme on the left shows how the stellar light propagates through a layer to the apertures and forms two spot images separated by x detector pixels. During finite exposure duration τ, the wave-front moves by $V\tau$, effectively increasing the sampled areas and reducing the atmospheric tilts. The scheme on the right relates the differential tilt between the two apertures α to the overall wave-front curvature.

Principle of operation. Differential Image Motion Monitor (DIMM) is an instrument to measure the Fried parameter r_0 or, equivalently, the seeing ε_0 or the C_n^2 integral over the whole atmosphere. Usually, a DIMM consists of a small telescope with a 2-aperture mask in front of it (Fig. 1). One hole is equipped by a thin-edge prism to separate the images of a bright star. This double image is recorded many times by a CCD detector with short (5-10 ms) exposures. Centroids of each spot are calculated and their differential variance (in detector pixels) is then computed over a series of images, typically of 1-min. duration.

A DIMM is not sensitive to the telescope shake and guiding errors (to the first order). Its field of view is usually wide (few arcminutes), easing the pointing tolerance. These features and relative simplicity contribute to the popularity of this instrument, which became a standard for seeing measurements.

Average separation between the spots is determined by the DIMM optics (prism and telescope focus), but random fluctuations of the separation are caused by the wave-front tilts at the apertures produced by turbulence. Knowing the angular detector pixel size p, we convert the differential centroid fluctuations in pixels to tilts α in radians. To the first order, this tilt is related to the overall wave-front curvature over the full aperture (Fig. 1, right). Differential variance σ^2_α in the direction parallel to the holes' centers is called *longitudinal*, in the orthogonal direction – *transverse*. These measured quantities are related to r_0 by the formula

$$\sigma^2_\alpha = K(\lambda/D)^2(D/r_0)^{5/3}. \tag{1}$$

Here D is the aperture diameter, the variance σ^2_α is measured in square radians, and the coefficient K depends on the holes' separation (baseline) B, direction (longitudinal/transverse) and some other factors (Tokovinin, 2002; Tokovinin & Kornilov, 2007). The calculated r_0 refers to the wavelength λ. It is strongly recommended to use $\lambda = 5\ 10^{-7}\,\mathrm{m}$ as a standard. The r_0 parameter is often replaced by the *seeing* $\varepsilon_0 = 0.98\lambda/r_0$. The two estimates of the seeing (longitudinal and transverse) are averaged. The seeing is multiplied by the $(\cos\gamma)^{3/5}$ to correct for the zenith distance γ at the moment of data acquisition. Standard DIMM data is a sequence of seeing ε_0 (at zenith, $\lambda = 500\,\mathrm{nm}$) as a function of universal time, complemented by additional (non-standard) parameters relevant to the data quality control (γ or air mass, fluxes, average separation between spots, Strehl ratios, scintillation index, etc.).

Formula (1) is valid for the Kolmogorov turbulence and instantaneous (zero) exposure time. The first assumption is good at spatial scales from D to B relevant to a DIMM. The measured variance is always biased by finite exposure time, detector noise, etc. Controlling and correcting biases in a DIMM is a complicated issue treated in (Martin, 1987; Vernin & Muñoz-Tuñon, 1995; Tokovinin, 2002; Tokovinin & Kornilov, 2007).

For **calibration** of a DIMM, we need to know D, B, p. For **de-biasing** the data, we need to know the detector readout noise, some parameters of the spots and of the centroid algorithm. The exposure-time bias can be either estimated by comparing quasi-simultaneous data with different exposure times (e.g. by binning adjacent images) or reduced to an acceptable level by using exposures shorter than 5 ms. The most troublesome bias is caused by the interaction between scintillation and imperfect DIMM optics. This bias depends on the usually unknown turbulence profile and aberrations. The only way to avoid it is to maintain a nearly diffraction-limited quality of the spots' images, quantified by their Strehl ratios. Even with such a control (e.g. both Strehls above 0.6), obtaining absolute accuracy of 10% or better may be difficult (Tokovinin & Kornilov, 2007; Wang et al., 2006). The problem is related to the high-altitude turbulence that produces scintillation and is not well described by the standard weak-perturbation theory, while the low-altitude turbulence is measured more accurately. We may say that the *weighting function* of a DIMM (its response versus altitude) is always one at low altitudes, but becomes somewhat uncertain at higher altitudes due to aberrations and propagation.

The isoplanatic angle θ_0 can be measured approximately from the flux fluctuations (scintillation index) if $D \sim 0.1\,\mathrm{m}$. The atmospheric time constant τ_0 can be estimated if the effective wind speed is known, but it is never actually *measured* by a DIMM. Fluxes in the spots can be used to detect clouds or to determine extinction. All these extra data products are not inherent to the DIMM method.

The hardware implementation of a DIMM can differ in many ways from the typical case described above. Instead of a prism, the spots can be split by mirrors or lenses inside the instrument, as in a MASS-DIMM (Kornilov et al., 2007), or imaged by two separate telescopes. The detectors can be one- or two-dimensional, with or without image intensification, etc. A DIMM can be considered as a 2-aperture Shack-Hartmann wave-front sensor, so this method can be applied to adaptive- or active-optics systems to measure the seeing in a large telescope.

Errors in the DIMM implementation or use are most often caused by the imperfect optical quality, e.g. by focus changes due to temperature, poor optical alignment, or even intentional defocus. A common error is to confuse the longitudinal direction with the direction parallel to the spots (instead of the baseline). In some DIMMs, the need to correct the exposure-time or noise biases is neglected. Aperture diameter D of at least 0.1 m is recommended, otherwise the diffraction and spectral bandwidth affect the DIMM weighting function. The detector angular pixel size must be of the order $\lambda/(2D)$ to sample the spots correctly.

References

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