Monitoring of the atmospheric turbulence profiles for the specification of ELTs adaptive optics systems

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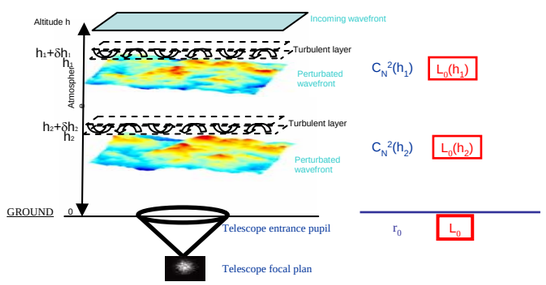
The futures large telescopes will be certainly equipped with Multi-Conjugate Adaptive Optics systems. The optimization of the performances of these techniques requires a precise specification of the different components of these systems. Major of these technical specifications are related to the atmospheric turbulence particularly the structure constante of the refractive index $C_n^2(h)$ and the outer scale $L_0(h)$. New techniques based on the moon limb observation for the monitoring of the $C_n^2(h)$ and $L_0(h)$ profiles with high vertical resolution will be presented.

A new monitor PBL (Profileur Bord Lunaire) for the extraction of the $C_n^2(h)$ profile with high vertical resolution has been developed. This instrument uses an optical method based on observation of the moon limb with a DIMM configuration (Differential Image Motion Monitor). Indeed, in the PBL the lunar limb is observed through two sub-apertures of 6cm separated by a base of ~30cm. The moon limb offers a continuum of stars at different angular separations allowing the scan the atmosphere with a very high resolution. The angular correlation along the lunar limb between of the differential distance between the two images of the lunar edge leads to the $C_n^2(h)$ profile. The other parameters of turbulence are also accessible from this instrument as the profile of outer scale, the seeing and isoplanatic & isopistonic domains. The PBL succeeded to our first moon limb profiler MOSP (Monitor of Outer Scale Profile) which was developed mainly for outer scale profile extraction. Several campaigns have been carried out with MOSP particularly at Mauna Kea Observatory (Hawaii) and Cerro Paranal in Chile.

The PBL instrument has been installed at Dome C in Antarctica since January 2011. In addition to this winterized PBL for Dome C, a second copy of this instrument has been developed for mid-latitude sites. A first campaign with this light version of PBL, was carried out at the South African Large Telescope (SALT) Observatory in August 2011.

$C_n^2(h)$ & $L_0(h)$ profiles and their integrated values at ground



The integrated parametersat ground level are related to the vertical distribution in the atmosphere:

$$\int dh C_n^2(h) = 0.06\lambda^2 r_0^{-5/3} \quad \text{and} \quad \mathcal{L}_0 \approx \left[\frac{\sum_h \delta h C_n^2(h)\mathcal{L}_0(h)^n}{\sum_h \delta h C_n^2(h)}\right]^{(1/n)}$$

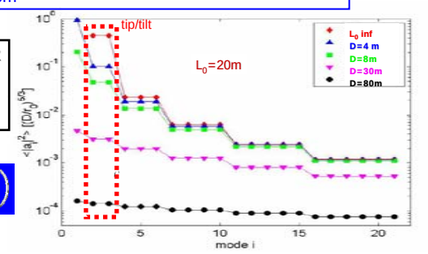
where the value of the exponent n depends on the experimental spatial filtering.

Implications of $C_n^2(h)$ & $L_0(h)$ on AO systems:

- ✓Number of μlenses & actuators
- ✓Position of the DMs
- ✓Stroke of deformable mirrors optically conjugated at different altitudes of the atmosphere.
- ✓ Need of tip/tilt system

Variance of the Zernick modes for different D/L_0 in the case of von Kàrmàn model

$$\varphi(\vec{r}) = \sum_{i=1}^{N} a_i Z_i\left(\frac{\vec{r}}{R}\right)$$

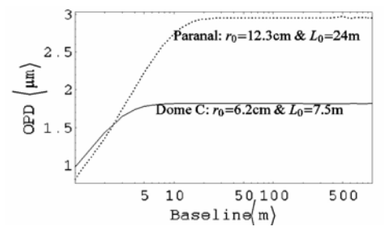


Implications of $C_n^2(h)$ & $L_0(h)$ on interferometry:

- ✓ Fringe excursion: optical path difference (OPD) between the two arms of the interferometer.
- ✓ Isopistonic angle: domain where the piston (OPD) remains coherent between the reference star and the observed object.

Dome C	σ_{opd}
h > 0 m	1.8 μm
h > 30m	0.6 μm

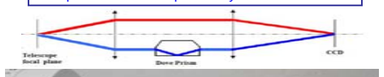
Paranal	σ_{opd}
h > 0 m	3 μm

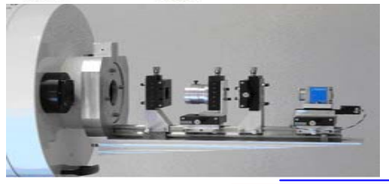


OPD versus baseline for an interferometer of 1m telescope diameter in the case of typical conditions of Dome C and Paranal.

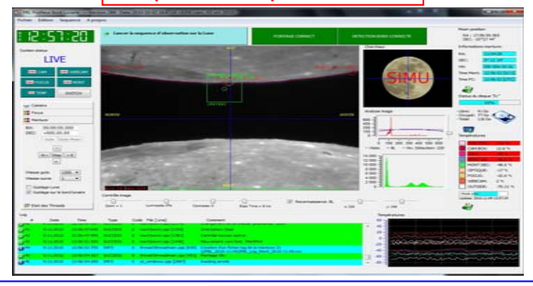
PBL Optical device

PBL is a DIMM obseving the moon limb consisting of 2 sub-apertures of 6cm separated by ~30cm.





Example of PBL acquisitions



Profilometry with PBL

PBL measures the covariance of the difference between the two moon limb fluctuations at different angular separations θ :

$$C_{\Delta\alpha}(\theta) = \langle [\alpha_1(\theta_0) - \alpha_2(\theta_0)][\alpha_1(\theta_0+\theta) - \alpha_2(\theta_0+\theta)] \rangle$$

For the whole atmosphere: $C_{\Delta\alpha}(\theta) = \int dh K_\alpha(B,h,\theta)$

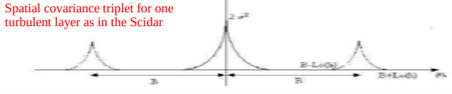
The Kernel K_α is function of spatial covariances (triplet):

$$K_\alpha(B,h,\theta) = 2C_\alpha(\theta h) - C_\alpha(B-\theta h) - C_\alpha(B+\theta h)$$

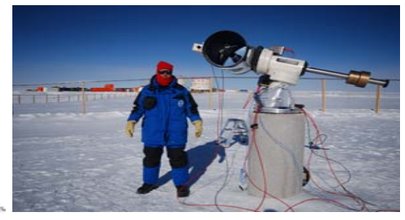
The spatial covariance for one turbulent layer:

$$C_\alpha(B) = 1.19\sec(z) C_N^2(h) \int f^{-3}\left(f^2 + \frac{1}{L_0^2(h)}\right)^{-11/6} \left(J_0(2\pi fB) + J_2(2\pi fB)\right)\left[\frac{2J_1(\pi Df)}{\pi Df}\right]^2 df$$

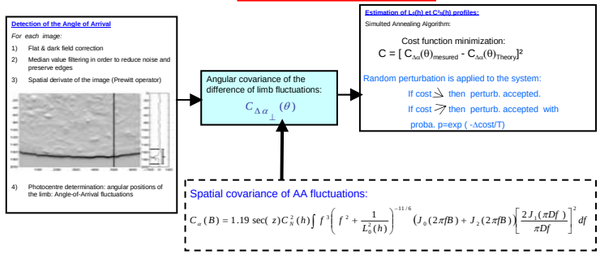
Spatial covariance triplet for one turbulent layer as in the Scidar



PBL Instrument at Dome C Winter 2011

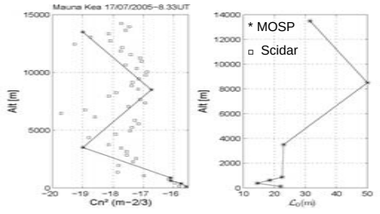


Data processing



Results: From MOSP towards PBL

Estimated $C_n^2(h)$ and outer scale profiles at Mauna Kea with MOSP(July 2005). Comparison to simultaneous measurements with the Scidar give an excellent agreement. The resolution will be enhanced with the PBL.



PBL Instrument at SALT Observatory: August 2011

A very important volume of data is continually collected at Dome C with PBL. But due to a very limited Internet connection of Concordia station, we cannot have access to this database. We have to wait the summer campaign to recover it. In the meanwhile, a mid-latitude version of PBL has been developped and used for the first time at the Sutherland Observatory which is the site of 10m telescope of South-Africa (SALT) in August 2011. Simultaneous observations with the SALT MASS-DIMM were carried out for direct comparisons. The data processing of this campaign is now in progress and the results will be published as soon as possible.

References:

1. J. Borgnino, 2010, Proc. of OTAM meeting, p. 42-49
2. R. Conan *et al.*, 2000, Proc. Spie, 4006, p.963-973
3. J. Maire, A. Ziad *et al.*, 2007, MNRAS, 377, p.1236-1244
4. W. Dali-Ali, A. Ziad *et al.*, 2010, A&A, 524, A73