Measurement of the optical relevant parameters for high angular resolution astronomy with the Generalized Seeing Monitor (G.S.M.)

R. Conan[1], A. Ziad[1], A. Tokovinin[2], R. Avila[1], J. Borgnino[1] and F. Martin[1]

[1] *U.M.R. 6525 Astrophysique, Université de Nice-Sophia Antipolis, Parc Valrose, 06108 Nice Cedex 2, FRANCE*

[2] *Sternberg Astronomical Institute, Universitetsky prosp., 13, 119899 Moscow, Russia*

Abstract. The Generalized Seeing Monitor (G.S.M.) is a recent instrument dedicated to the study of the optical effects of atmospheric turbulence. The last developments of the instrument are presented here.

1. Introduction

Among the parameters useful to qualify an astronomical site, we note the seeing angle, the isoplanatic angle, the coherence time and the wavefront outer scale $\mathcal{L}_0$. This last one is the less well-known and in the past years, experimental values were controversial. $\mathcal{L}_0$ affects all the parameters of interest in High Angular Resolution technics. For example, short $\mathcal{L}_0$ lead to a decrease of the variance of the optical path difference (Davis et al. 1995) and the decorrelation of the angle of arrival occurs at a shorter distance than in a model with infinite $\mathcal{L}_0$ (Dekens et al. 1994). The Generalized Seeing Monitor (GSM) was built in order to extend our knowledge of this parameter as its fluctuations over one night or its variation range for instance. The GSM gives also the seeing angle and the scintillation index. After the first mission at La Silla observatory (Chile) in August-September 1997, new processing of the data gave an estimation of the isoplanatic angle and a measure of the wind associated with the predominant turbulent layers.

2. The GSM instrument

The GSM uses four 10 cm diameter telescopes in a L-shaped layout (Figure 1). The telescopes 1 and 2 are mechanically coupled on the same mount. They detect angle of arrival (AA) fluctuations as described by Martin et al. (1994). The $\mathcal{L}_0$ value is deduced from the AA spatial covariance. The four telescopes of the GSM allow six baselines to give six points on the AA spatial covariances. Beforehand, a set of theoretical AA covariances versus baselines and $\mathcal{L}_0$ has been computed from the Von Kàrmàn power spectrum of the phase fluctuations of the electromagnetic wave. The experimental covariances are plotted on this set and an interpolation gives the $\mathcal{L}_0$ values measured with each covariance. The final $\mathcal{L}_0$ value is taken as the median of the six values. r_0 can be deduced from the AA variance on each telescope or from the differential AA variance on coupled telescopes (Roddier 1981). Scintillation index is estimated from the flux recorded in each telescopes. The first mission of the GSM took place at La Silla observatory (Chile) from August 26 to September 20 1997 (Martin et al. 1998). During this period, the GSM worked 19 nights and for each one the three parameters were measured. Figure 2 presents the results of the night of September 13, r_0 is converted to its equivalent FWHM seeing angle ε. The median values of $\mathcal{L}_0$ and ε for the whole mission are 25 m and 1.63 arcsec respectively. The value of ε is worst than the typical values registered at La Silla and the value of $\mathcal{L}_0$ is of the order of the now commonly admitted values for $\mathcal{L}_0$. After this first mission, a deeper analysis has been undertaken which shows the ability of the GSM to estimate the isoplanatic angle and to measure the speed and the direction of the winds which carry the turbulence in the strongest layers of the atmosphere. Section 2 and 3 present these new aspects of the GSM.

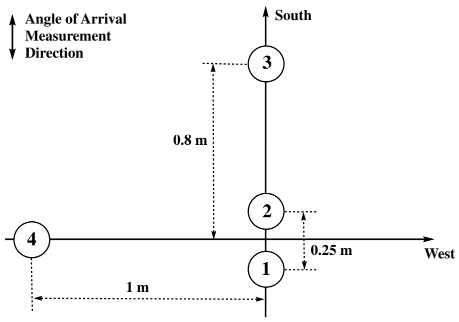

Fig. 1 : Layout of the GSM

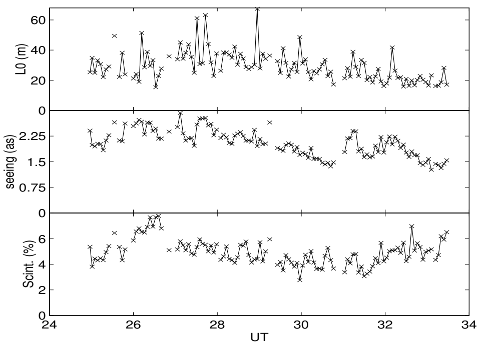

Fig. 2 : Night 09.13.97 : $\mathcal{L}_0$, ε and σ_I^2

3. Isoplanatic patch

The principle of the estimation of the isoplanatic angle θ is based on the similitude between the theoretical expressions of θ and of the scintillation index σ_I^2:

$$\theta^{-5/3} = 114.9\lambda^{-2}\,(\cos\omega)^{-8/3}\int_0^H dz\; z^{5/3}C_n^2(z),$$

$$\sigma_I^2 = 9.55\lambda^{-2}\int_0^H dz\; W(z)C_n^2(z).$$

ω is the zenith angle. $W(z)$ is the weighting function which depends on the point spread function (PSF) of the instrument $G(f)$ (f is the spatial frequency):

$$W(z) = \int_0^{+\infty} df f^{-8/3}\sin^2(\pi\lambda z f^2)G(f).$$

If $W(z)$ varies like $z^{5/3}$, the scintillation index can be used to estimate θ with the following expression :

$$\theta^{-5/3} = 12.03\,(\cos\omega)^{-8/3}\,\sigma_I^2 \frac{z_0^{5/3}}{W(z_0)}.$$

where z_0 is the altitude where a single turbulent layer should be placed to give the same isoplanatic angle than the whole atmosphere. This is the method used for the isoplanometers (Loos & Hogge 1979, Krause-Polstorff et al. 1993) for which the PSF was optimized in order to obtain the adequate behavior for the weighting function. Simulations with C_n^2 profiles, theoretical (Lukin et al. 1997) as well as measured with the Generalised Scidar (Avila et al. 1998), showed than the approximation to a $z^{5/3}$ dependence for the GSM weighting function is quite good. And the error on the θ values are less than 1 % for an altitude $z_0 = 10$ km.

4. Characterization of the wind of the predominant turbulent layers

The wind velocities are extracted from the spatio-temporal correlation of the AA :

$$C_{\alpha_i\alpha_j}\left(\overrightarrow{B}, \tau\right) \qquad i,j = 1,2,3,4 \text{ and } i \neq j.$$

$\overrightarrow{B}(B,\eta)$ is the vector linking up the centers of the pupils i and j and τ the delay between the records of α_i and α_j. If we supposed that the frozen-flow (Taylor hypothesis) is verified for each turbulent layer, the correlation is written as :

$$C_{\alpha_i\alpha_j}\left(\overrightarrow{B}, \tau\right) = C_{\alpha_i\alpha_j}\left(\overrightarrow{B} - \overrightarrow{v}\tau\right),$$

where $\overrightarrow{v}(v,\gamma)$ is the wind which carries the turbulence in the layer. This last expression shows that in fact the spatio-temporal correlation of the AA is a cut of the spatial covariance of the AA along a plane given by the wind direction. Each peak in the correlations is due to either a single turbulent layer or a set of layers having winds, all blowing at the same speed and in the same direction. With the GSM, 6 correlations corresponding to the 6 baselines are computed and the position of each peak gives the time taken by the same turbulent structure to be detected successively by 2 telescopes separated by a distance B. This delay is related to the projection of the wind vector on the baseline by : $\tau = \frac{B\cos(\gamma-\eta)}{v}$ (Avila et al. 1997).

Two non-colinear baselines permit to deduce the wind of the layer(s). But the altitude of the layers and their relative strength can not be deduced. There is no easy way to analyze for example the relative amplitude of the peaks because a peak amplitude depends on the C_n^2 and on the $\mathcal{L}_0$, but also on the relative orientation between the baseline and the wind direction. If the wind blows in the direction of the baseline, the spatial covariance is cut at its maximum but if both directions are perpendicular, the peak could be undetected even if it is the peak related to the turbulent layer with the strongest C_n^2.

At La Silla observatory, almost each night, two peaks were noticed showing two predominant turbulent layers and giving two winds. One of them is strongly correlated with the wind measured by the ground weather station, related to the surface layer. The other wind is stable with quasi constant speed and direction during the night like a wind in the free-atmosphere.

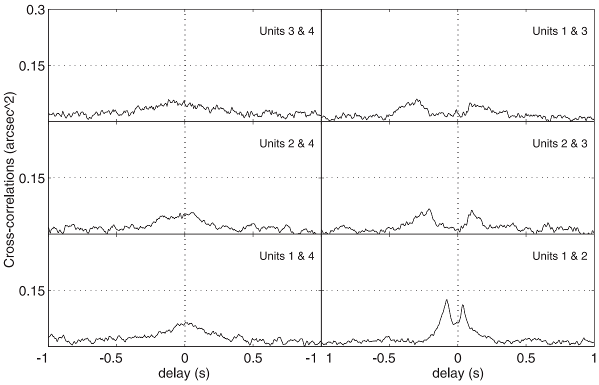

Fig. 3 : Examples of correlations for night 08.28.97 at 23:54 UT showing two peaks almost symetric indicating two layers moving in opposite direction

5. Conclusion

The GSM is now a complete instrument which is able to provide a set of fundamental parameters for H.R.A.. It works around the world in order to obtain a data bank from the existing and future major astronomical sites. Since the first mission at La Silla observatory (Sept. 97), data have been already collected from Oukaimden in Morocco (April 1998) and from Maydanak in Uzbekistan (July 1998), and before the end of the year two missions in Chile are scheduled : at Cerro Pachon, the site of the Gemini South telescope and at Cerro Paranal, the ESO observatory where the VLT operates.

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