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Shack-Hartmann wavefront sensor design for optical communications in strong scintillation conditions

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In the case of an optical link with a LEO satellite, it is crucial to maximize the duration of the downlink, even at low elevations, in order to transfer the largest amount of data possible at each pass. However, in this context, amplitude fluctuations (or scintillation) are challenging the operation of Adaptive Optics (AO) systems, starting with their wavefront sensing subsystems.
Indeed, low elevations imply a strong perturbation regime as the propagation distance through turbulent atmosphere layers increases, causing log-amplitude variance to reach saturation, i.e. with propagation conditions beyond Rytov's approximation [1].
In the case of a Shack-Hartmann Wavefront Sensor (SHWFS), scintillation induces a wide intensity range across the pupil resulting in some subapertures being saturated and other being extinguished (cf. Figure). Besides, when the intensity distribution is non-uniform in a given subaperture, the slope measurement is biased [2]. Moreover, the point-spread functions of some subapertures suffer from diffraction effects making it difficult to compute the centroids and to obtain accurate slope measurements.
We have performed propagation simulations through strong atmospheric perturbations, representative of daytime LEO downlink with r0 ranging from 4cm to 1cm, and $\sigma\chi$ Rytov
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ranging from 0,08 to 0,9 to

observe the effect of increasing scintillation.
We then study the effect on wavefront sensing accuracy of the sampling of the complex amplitude by the subapertures grid. Without taking noise into account, we highlight the improvement brought by oversampling the SHWFS on robustness and accuracy of the measurements.
Finally, regarding the issue of the large intensity variations due to scintillation, we present a centroid estimator able to perform well from detector noise regime to photon noise and saturation regime.

Astrophysics Field

Day constraints

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