# Including the pyramid WFS non-linearities into a fast PSD error breakdown tool

Romain Fetick*†[1,2], Vincent Chambouleyron‡[3], and Cedric Taissir Heritier§[1,2]

[1]ONERA – ONERA, 92320 Châtillon – France
[2]Laboratoire d'astrophysique de Marseille – Aix Marseille Univ, CNRS, LAM, Laboratoire d'Astrophysique de Marseille, Marseille, France – France
[3]University of California, Santa Cruz – United States

**Abstract**

Adaptive optics (AO) for astronomy requires to lock on fainter and fainter sources, and thus to increase the sensitivity of wavefront sensors. The pyramid sensor, and more generally the Fourier Filtering wavefront sensors (FFWFS), become the baseline for current or future AO systems since they achieve higher sensitivity than the legacy Shack-Hartmann one. The drawback of the sensitive FFWFS is to be highly non-linear, since the response drops dramatically as the incoming wavefront error increases.
Designing from scratch a new AO system, foreseeing its performances and then comparing its on-sky performances with the expected ones requires analytical expressions (if available) and simulations. The end-to-end simulation tools are particularly suited to describe the full response of the AO system, including its non-linearities. Even though the end-to-end simulations are highly representative of the real response of the system, they are subject to drawbacks:

- Long exposure PSF requires high computation time and CPU/GPU resources

- Temporal sampling must be managed with care, since a poor interpolation of the random phase between pixels may induce high frequencies artifacts

- AO effects are combined all together, making it difficult to disentangle for targeting one specific effect. Multiple simulations are then necessary to identify tendencies and response to different observing conditions.

We thus propose a simulation of the pyramid based on the phase power-spectral-density (PSD), often called "Fourier plane" simulations. These simulations do not suffer the issues mentioned above, and have been used in tools such as TIPTOP. The novelty of our method is to take into account the non-linearities through the optical gains of the pyramid by a recursive computation of the PSF:

1- Compute the conventional error terms (fitting, aliasing, temporal, noise)

*Speaker
†Corresponding author: romain.fetick@lam.fr
‡Corresponding author: vchambou@ucsc.edu
§Corresponding author: cedric-taissir.heritier@lam.fr

2- Compute the PSF and then the optical gains using the convolutive model

3- Include these optical gains in the error transfer function, and iterate to step 1
We show good agreement between our method and end-to-end simulations for estimating long-exposure PSF, with typical computation time of few minutes for large systems.

**Keywords:** pyramid, optical gain, simulation