LGS Elongated Spot Generation in OOMAO

L. Blanco

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1 Introduction

This memo describes the way Laser Guide Star (LGS) elongated spots are computed, at the Wavefront Sensor (WFS) detector level, in the OOMAO end-to-end simulator.

The basic idea is to propagate through the atmosphere a single point source located at the mean Sodium layer altitude, using pre-existing OOMAO tools, and convolve, at each WFS subaperture, the atmospheric PSF with a spot kernel, containing the elongation information and pre-computed using the geometrical properties of the problem.

This allows us to de-couple what happens at the lenslet level and what happens at the detector level and allows us to deal with very large elongations and easily modify the spot sampling, which was not easily feasible previously.

2 Sodium profile

Sodium intensity profiles are discretised using a finite number n_{Na} of points, each point being associated with its altitude value a_j and an index j. The number of points used to sample the Na profile is arbitrary, provided that the profile sampling is finer than the subaperture detector sampling.

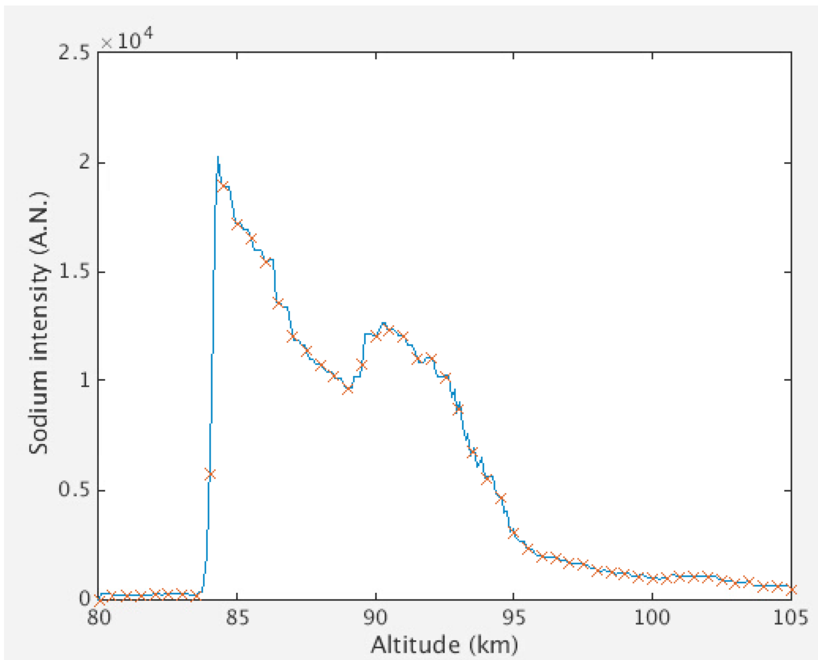

Figure 1: Discretized Sodium profile. Blue: profile sampled with 250 points (height resolution = 100m). Red crosses: profile sampled with 50 points (height resolution=500m).

Sodium profile intensity is a vector $\{I_1, ..., I_j, ..., I_{n_{NA}}\}$ with n_{Na} intensity values. The intensity values are normalized ($\sum I_j = 1$).

3 Problem description and geometry

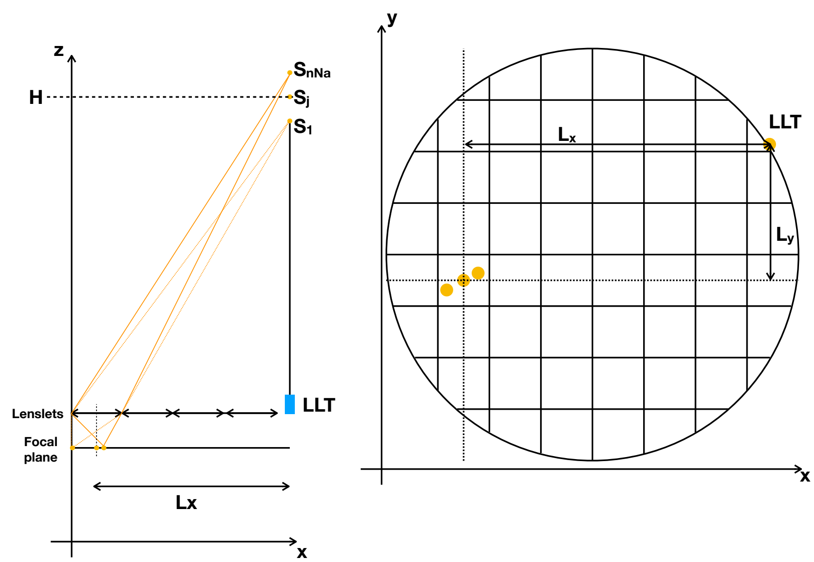

Figure 2: Problem geometry. Left: XZ view of the LGS elongation. The LLT is at the right edge of the telescope pupil. H is the subaperture lenslet conjugation altitude. 3 individual, yellow, spots s are shown with their image at the focal plane of the leftmost subaperture. Right: XY view of the telescope pupil with the LLT at the top right edge of the pupil. The three individual spot images are shown in yellow. L_x and L_y are the distance from the LLT to the considered subaperture in the x and y direction.

The laser guide star object is modeled as a finite number nNa of 2D objects o_j aligned with the Laser Launch Telescope (LLT) and at altitude ranging from 80 to 105km.

At the focal plane of the m-th subaperture, the image of an individual 2D object o_j will be shifted, with respect to the subaperture optical axis, by a distance that depends on the altitude a_j of the object and on the location of the subaperture with respect to the LLT.

4 Image model and spot kernel generation

The image i^m at m-th subaperture focal plane can be written as:

$$i^m = \sum_{h=1}^{n_{Na}} \left[\left(I_j \times o_j * \delta(x_j^m, y_j^m) \right) * h^m \right], \tag{1}$$

where:

- $*$ is the convolution product;
- I_j is the normalized Na return flux from altitude a_j;
- o_j is the 2D LGS object at altitude a_j;
- x_j^m (respectively y_j^m) is the shift induced, at subaperture m, by the parallax on the image of o_j in the horizontal (respectively, vertical) direction, with respect to the subaperture optical axis;
- $\delta(x, y)$ is a Dirac distribution centered at (x, y);
- h^m is the atmospheric PSF of the m-th subaperture.

The convolution product being linear and since the atmospheric PSF does not depend on the altitude a_j, one can write:

$$i^m = h^m * \sum_{h=1}^{n_{Na}} \left(I_j \times o_j * \delta(x_j^m, y_j^m) \right), \tag{2}$$

$$i^m = h^m * K^m, \tag{3}$$

where $K^m = \sum_{h=1}^{n_{Na}} \left(I_j \times o_j * \delta(x_j^m, y_j^m) \right)$ is the spot kernel corresponding to the m-th subaperture.

x_j^m and y_j^m are computed using simple geometrical optics.

$$x_j^m = L_x^m \frac{H - a_j}{H.a_j}, y_j^m = L_y^m \frac{H - a_j}{H.a_j}, \tag{4}$$

where L_x^m is the distance from the LLT to the center of the m-th subaperture in the x direction, L_y^m is the distance from the LLT to the center of the m-th subaperture in the y direction and H is the subaperture lenslet altitude conjugation.

o_j contains the lateral extension of the LGS spot (due to the laser waist and upward propagation), nominally modelled as a 2D Gaussian.

Fig 3 show two examples of spot kernels, one with three LGS objects $\{o_1, o_2, o_3\}$ clearly separated in altitude, for the sake of illustration, and one with a continuous LGS object (i.e. spots closer together).

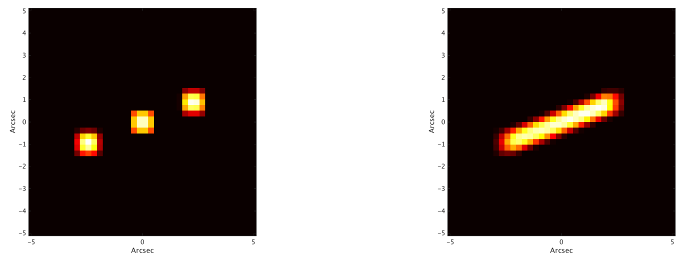

Figure 3: Two examples of spot kernels. Telescope diameter = 37m, LLT at the right edge of the telescope pupil, subaperture at the left edge of the telescope pupil, opposite from the LLT. Left: spot Kernel for 3 individual LGS (corresponding to Fig 2) objects at altitudes 87, 90 and 93km. Right: spot kernel for 51 individual LGS objects at altitudes evenly spaced from 87 to 93km. Subaperture conjugation altitude = 90km.

5 Subaperture image generation

The wavefront sensor image is computed subaperture per subaperture by convolving the image of a point source, located at the LGS spot location and propagated through the atmosphere, telescope and deformable mirror, with the corresponding elongated kernel K computed per 4.

The resulting sub-image is then binned to the desired sampling and cropped to the actual subaperture size to simulate subaperture truncation, if any. Shot noise and detector noise can be added and centroiding is performed on the final subimage.

Fig 4 shows examples of subaperture images for an Na profile discretised with only 3 points at altitudes 87, 90 and 93km, therefore discontinuous for the sake of illustration, and with a more realistic, continuous, case of 51 points.

Although not clearly visible on the figure, the images are actually slightly enlarged due to the convolution of the spot kernel K with the PSF of the subaperture.

6 Limitations and improvements to be made

- Downward attenuation in Z^2 oddly not taken into account (compensates with Th. Pfrommer measurements ?)
- Asterism has to be radial with respect to the LLT $\rightarrow$ not possible to shoot 6 LGS from 4 LLTs)
- Defocusing of the individual spots not at the lenslet conjugation altitude not taken into account $\rightarrow$ overestimation of the importance of the highest and lowest spot features - worst case

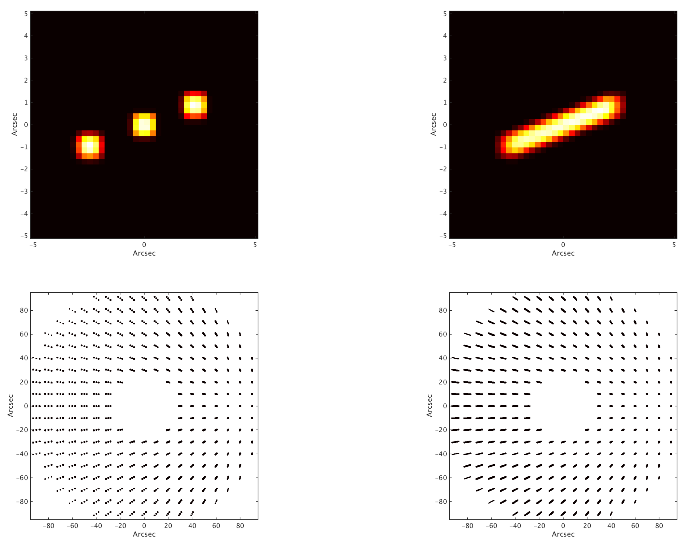

Figure 4: Top : Two examples of subaperture images corresponding to the kernels of Fig 3. The images are slightly larger than the spots due to the convolution by the PSF of the subaperture, as expected. Bottom: the corresponding footprints of the elongated LGS on the WFS detector (D=37m, only 19x19 subapertures for clarity.