PSF RECONSTRUCTION PROJECT OPERA PROJECT, FIRST RESULTS

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1. Code OPERA - development status

I wrote the code in 2002-2003 when I was at HIA/NRC, and had the opportunity to run it only once, on a single set of laboratory data. Now that I am using it intensively, I realize that its organization is not optimal, and there is a need to re-organize things here and there. What is very important though is that now the full algorithm, from circular buffers loading to PSF computation is complete, and functional.

2. First reconstructed PSF for Altair/Gemini

Julian Christou gave me Altairs's WFS and DM commands circular buffers for 20 nights in December 2009, for bright (mV$\leq$ 8) tuning NGS. Each set contains 61400 loop samples, at 1 kHz, so about 1 minute of data per night. This can be considered long exposure. I have run OPERA on these data for the middle of the K-band, at 2.125 microns. Conditions for the computation were the following:

(1) perfect telescope with central obscuration,
(2) I took into account the fitting error, the WFS spatial aliasing error, and the servo-lag error, the later assumed to be represented by the WFE mirror modes covariance matrix extracted from the WFS measurement circular buffer, translated into mirror modes coefficients,
(3) WFS noise is considered not an issue in the current bright NGS conditions, and will be included later, once we get access to dimmer NGS data.

2.1. **Mirror modes coefficients variances/RMS.** The residual WFE expressed in mirror modes coefficients RMS is shown in figure 1 for the 20 nights of December 2009. There is apparently much less variability of the tip-tilt modes than with the higher order modes, above the 2nd order. As it seems that the tip-tilt WFE is higher than what it would be if we extrapolate the high order trends toward tip-tilt, this seems to indicate that there is an excess of tilt error, possibly coming from vibrations. TBC.

2.2. **Tilt jitter and PSF.** For the night of Dec 16, tilt jitter was about 4 times (in variance) than what is seems to be on average. Was there a particular issue with wind / other vibrations during the night ? we would need to explore the telescope control system archive to tell. Anyway, this excess of tilt has a strong impact on the reconstructed PSF (see figure 2): the Strehl is lowered to 39% down from an average 66+/-7% for the other cases, and the PSF section (about 63 masec on average) has an elliptical shape of widths 92 masec and 75 masec, oriented along the 45 degrees diagonal. At least the PSF we have build represents well the tilt RMS values we found in the WFS data, so this is encouraging. It is important to note that the seeing we extracted from the DM commands was not affected by this excess of tilt, because tilt (and defocus) is systematically excluded from r_0 and L_0 estimates. In figure 2, right, we show how the FWHM is affected by the residual jitter. The line on the figure is a fit to the experimental values. This empirical relationship is very linear and is a good indication that the excess of FWHM is indeed due to a tilt jitter. Extrapolating the curve to the vertical axis, i.e. no residual tilt, we find that the FWHM would be, in this case, equal to 57 masec, i.e. exactly the diffraction limit FWHM for a 7.906 m aperture at K-band.

2.3. **Seeing and PSF.** The night of the 18th, the seeing was apparently bad, according to the seeing values estimated from the DM commands (1.4" instead of an average of 0.5" ± 0.2"). This is very apparent on the modes coefficients variances (figure 1), and as expected the Strehl measured on the reconstructed PSF is low, at 18%. The PSF halo is clearly increased too, see figure 3, left. In the same figure, right, we show the relationship between the K-band Strehl measured in the reconstructed PSF and the total variance (in μm^2) for all the 20 nights, and superimposed, the Strehl predicted using Marechal approximation on the total variance. The agreement is relatively good. Finally we show in figure 4 the measured K-band Strehl as a function of the measured seeing angle. Except for the case with the excess of tilt (Dec 16), the Strehl behaves as expected, and extrapolating the Strehl to a seeing angle of 0 asec (no turbulence seems to be grossly compatible with a Strehl of about 100%.

3. Next steps in the PSF-R project

To summarize, there is a good correspondence between what we see on the residual wavefront errors modes coefficients and the reconstructed PSF, demonstrating the validity of the approach. Next steps are (1) include an estimate of the telescope PSF, and compare with the actual NIRI/based PSF available for these 20 nights; (2) get noisier data with dimmer NGS, and include the noise covariance matrix in the PSF-R process.

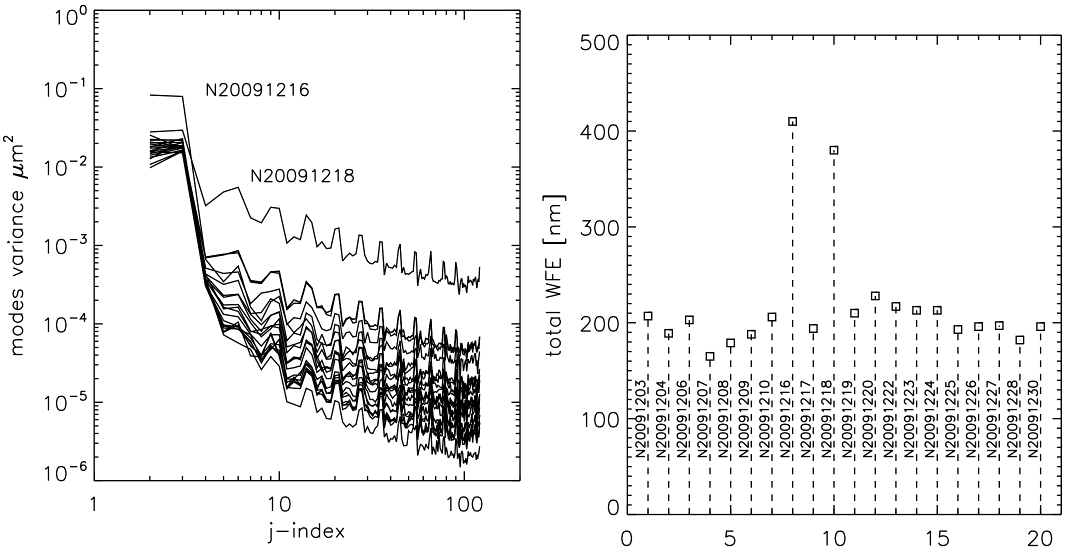


FIGURE 1. Left: variances of the mirror modes coefficients, in μm^2. Right: total WFE for the 20 nights, in nm. All the 20 nights are represented. The tag N20091216 indicates the night of December 16 (highest tilt WFE), and the tag N20091218 the night of December 18 (highest WFE at high orders).

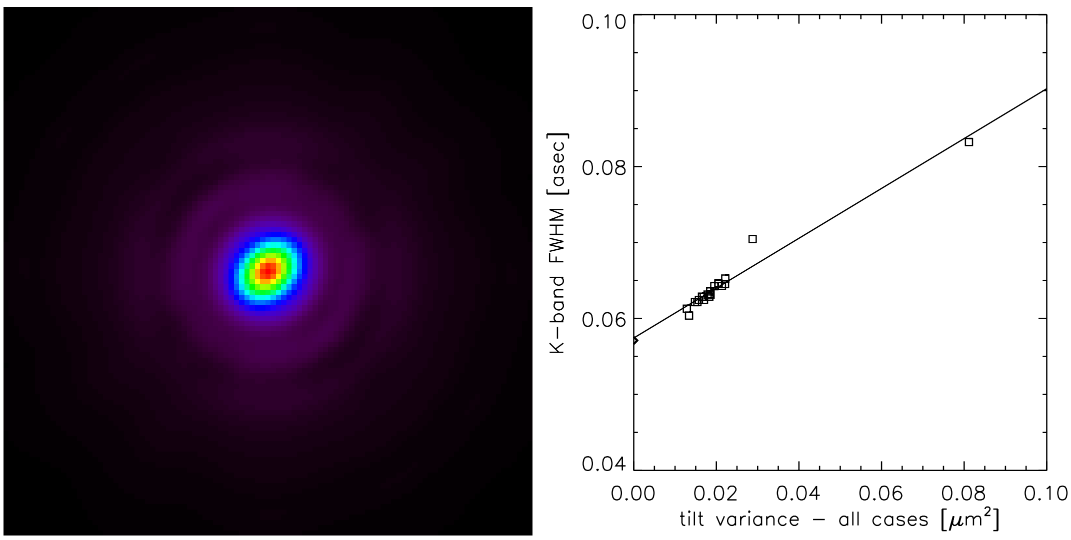
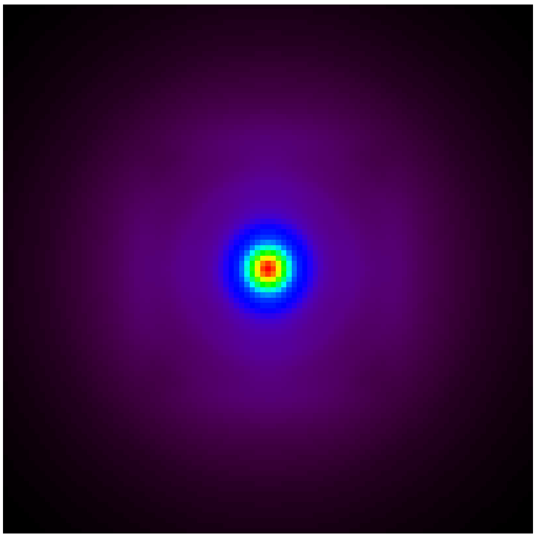


FIGURE 2. Left: December 16 reconstructed PSF. We show the square root of the PSF to increase the contrast in the wings. Right: K-band PSF FWHM, measured on the reconstructed PSF as a function of the tilt variance (average of tip and tilt) for the 20 nights. The line shows the best linear fit with the data.



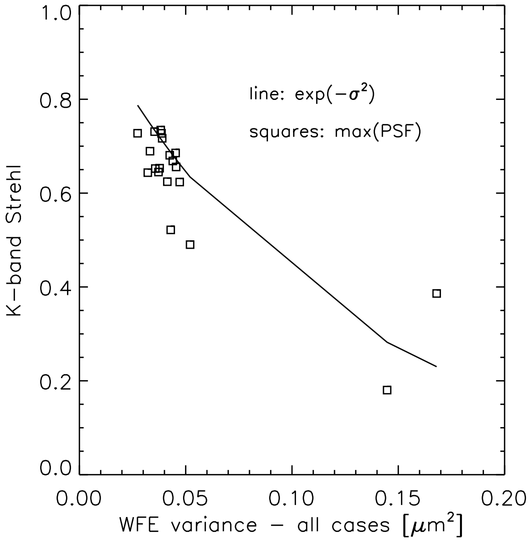


FIGURE 3. Left: December 18 reconstructed PSF. We show the square root of the PSF to increase the contrast in the wings. Right: K-band Strehl, measured on the reconstructed PSF, as a function of the overall WFE variance for the 20 nights. The line shows the best fit with the data.

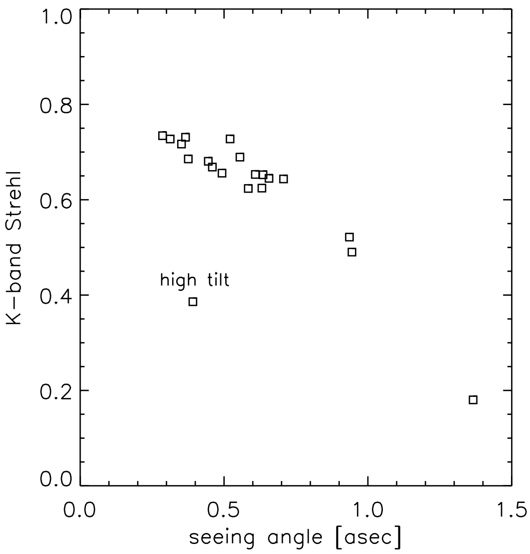


FIGURE 4. Strehl and seeing angle. Extrapolation to the case $w_0 = 0$ is compatible with a Strehl=1.

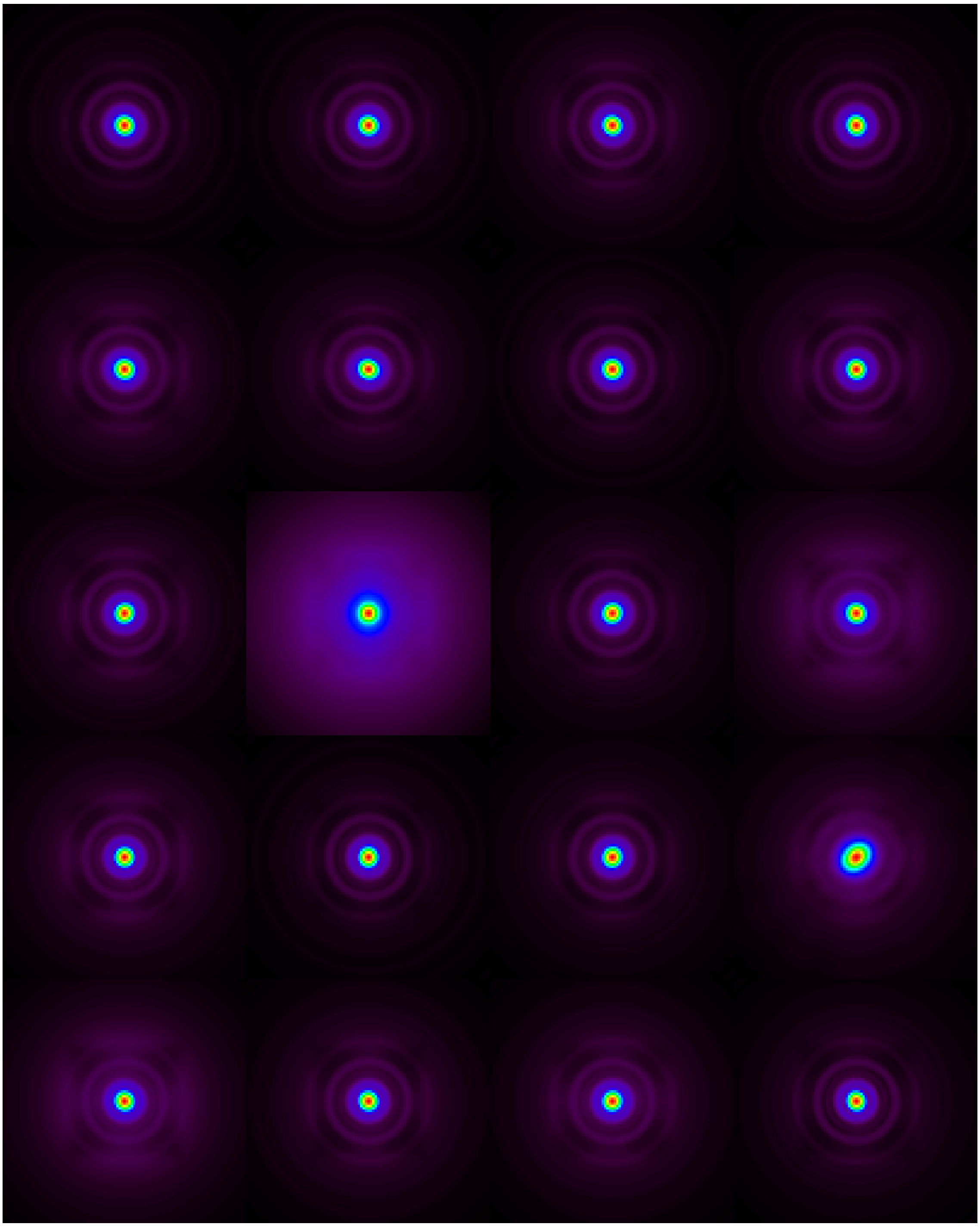


Figure 5. From bottom left to top right, the 20 nights PSF at K-band, with a sqrt intensity scaling.