Speckle lifetime in XAO coronagraphic images

Temporal evolution of SPHERE coronagraphic images

J. Milli[1], T. Banas[1], D. Mouillet[2], D. Mawet[3], J.G. Girard[1], A. Vigan[4], A. Boccaletti[5], M. Kasper[1], Z. Wahhaj[1], A.M. Lagrange[2], J.L. Beuzit[2], T. Fusco[4,6], J.F. Sauvage[4,6], R. Galicher[5]

INTRODUCTION

The major source of noise in high-contrast imaging is the presence of slowly evolving speckles that do not average with time[1]. The temporal stability of the point-spread-function (PSF) is therefore critical to reach a high contrast with extreme adaptive optics (XAO) instruments[2].

Understanding on which timescales the PSF evolves and what are the critical parameters driving the speckle variability allow to design an optimal observing strategy and data reduction technique to calibrate instrumental aberrations and reveal faint astrophysical sources[3]

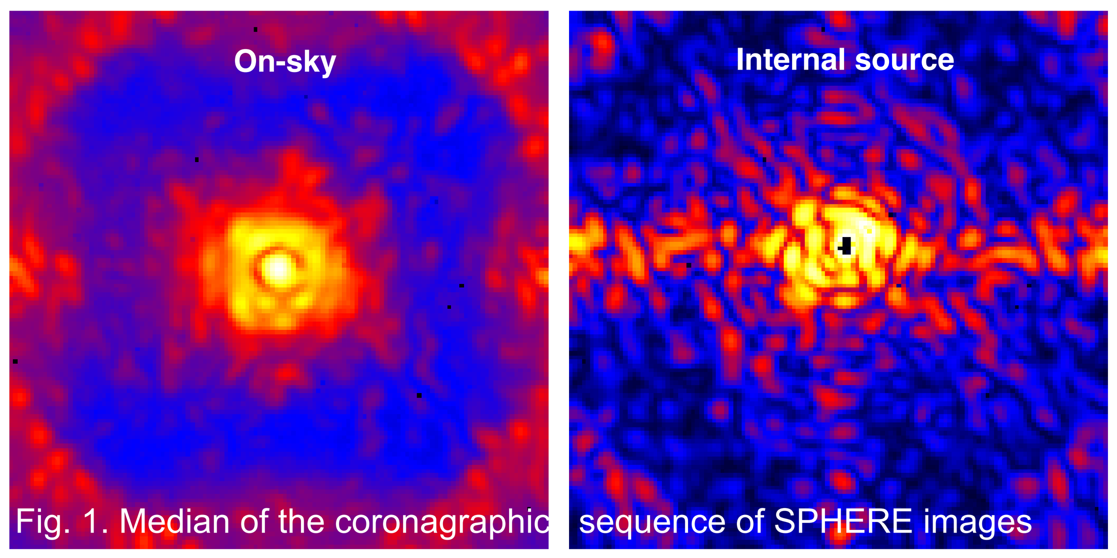

Fig. 1. Median of the coronagraphic sequence of SPHERE images

We aim here at analyzing empirically how coronagraphic images evolve with time in the well-corrected region of an XAO instrument, based on on-sky images, to complement existing laboratory measurements[4].

The observations were carried out with VLT / SPHERE[5] in pupil-tracking mode with the 185mas apodized Lyot coronagraph and the IRDIS camera in the H2 narrow-band filter (1.6μm) in good conditions (seeing 0.4", τ 4ms) with a Strehl ratio of 92%. A sequence of 5000 frames or 50min was obtained with a frame rate of 1.6Hz, and we repeated the acquisition shutter closed with an internal lamp for comparison (Fig. 1).

METHODS

For each pair of frames from the sequence (~10^7 pairs in total), we computed the Pearson correlation coefficient between the 2 frames of the pair (Fig. 2).

We represent the result in the form of a 1D curve of the correlation coefficient as a function of the time ellapsed between the 2 frames (Fig. 4) with a zoom over the first minute in Fig. 5

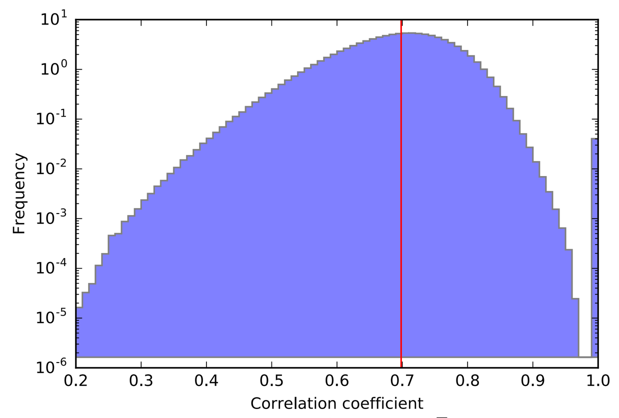

Fig. 2. Histogram of the 10^7 correlation coefficients

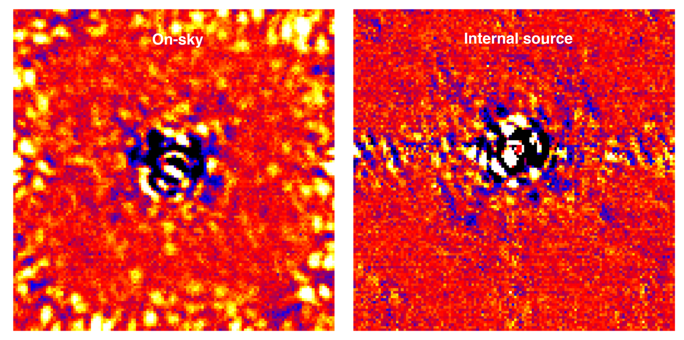

Fig. 3. One frame of the sequence after subtracting the temporal median.

This analysis was also done after subtracting the temporal median of the sequence (right panels in Fig. 4 and 5) to focus on the variable part of the PSF.

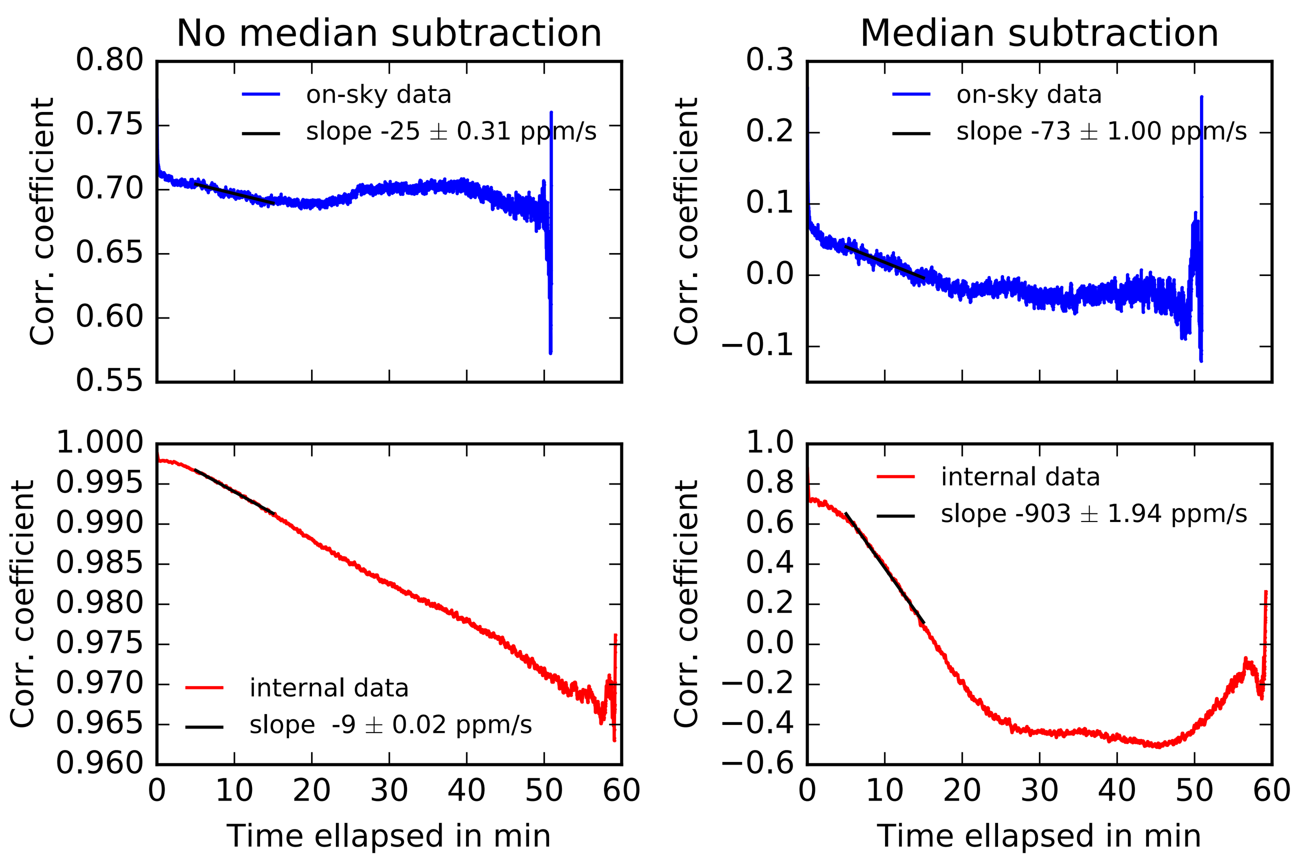

Fig. 4 Correlation coefficients and linear fits between 5 and 15min.

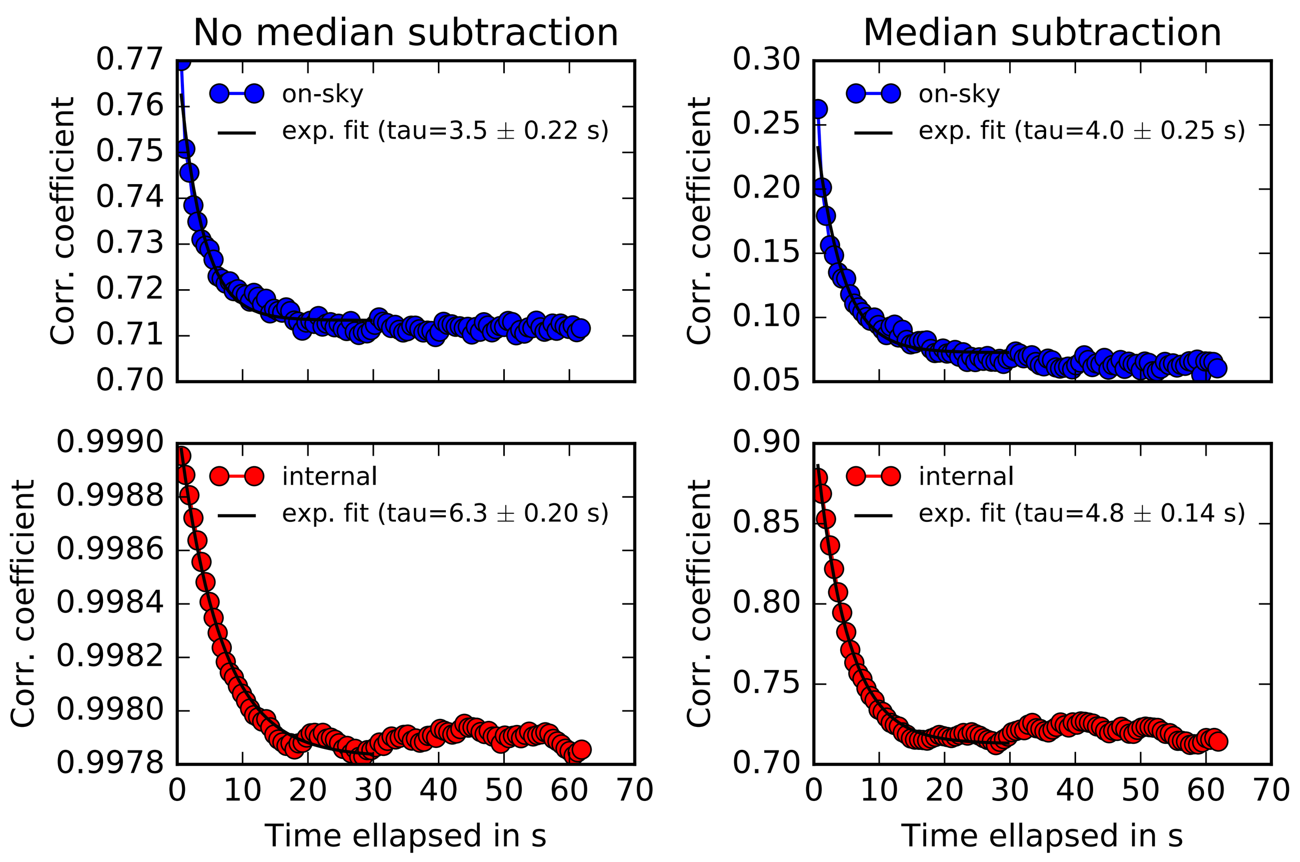

Fig. 5. Zoom of Fig. 4 over the first minute with an exponential fit of equation $Ae^{-t/\tau}+B$

RESULTS

We identify 2 regimes: a linear decorrelation from 5 to 30 min and a rapid drop in the correlation over a few seconds.

We show with a zonal analysis (in subregions of 3x3 λ/D) that the speed of linear decorrelation identified in Fig. 4 decreases with the distance to the source (Fig. 6 left), while the exponential decay identified in Fig. 5 is independent of the separation (Fig.6 right). This indicate that wavefront errors at low spatial frequencies evolve faster in the linear regime. The rapid decorrelation being also seen with the internal source, its origin cannot be the residual atmospheric wavefront errors[6] of timescale 0.6D/υ.

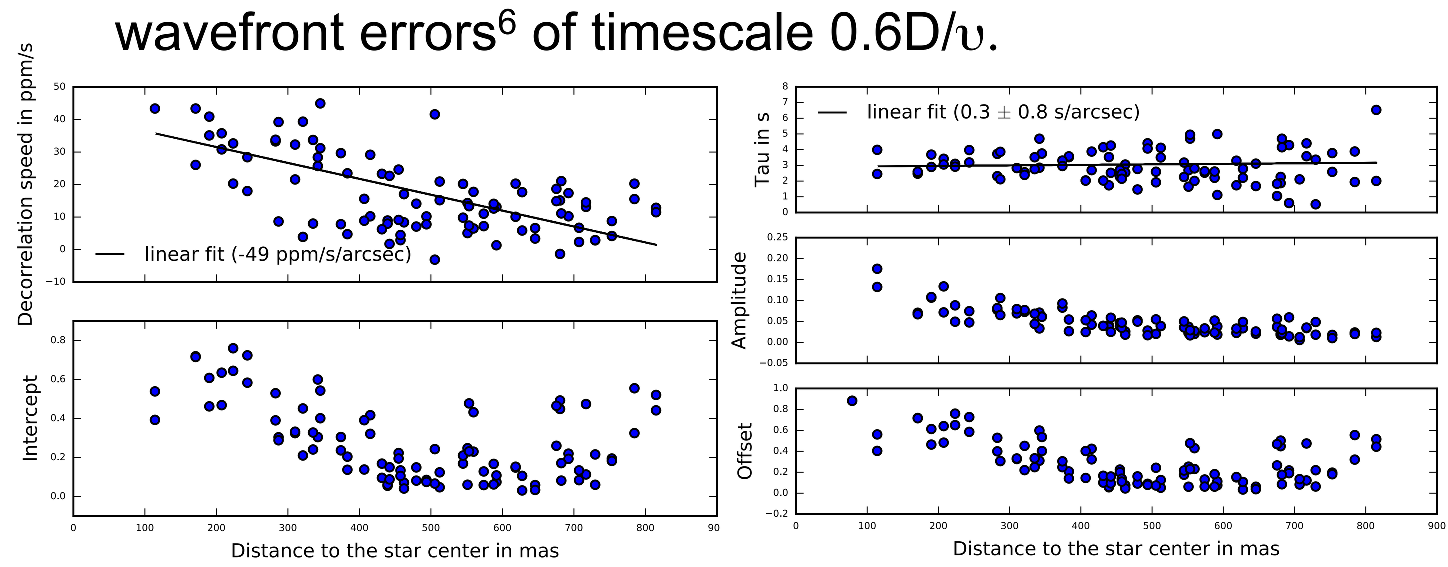

Fig. 6. Zonal analysis: parameters of the linear fit (left) and exponential fit (right) shown in Fig. 4 and 5 plotted vs the distance to the star for the on-sky sequence (no median subtraction).

CONCLUSIONS

1. **A linear decorrelation occurs between 5 and 30min, both on-sky and with the internal lamp. It evolves 3 times faster on-sky. The large-scale wavefront errors decorrelate faster in this regime.**
2. **A rapid decorrelation occurs in the first 4s, both on-sky and internally. Wavefront errors at all spatial scales evolve at the same speed.**

Further characterization is on-going to identify the source of these wavefront errors.

REFERENCES

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Affiliations: 1 European Southern Observatory (ESO), 2 Université Grenoble Alpes IPAG, 3 Department of Astronomy Caltech, 4 Aix Marseille Université CNRS LAM , 5 LESIA Observatoire de Paris CNRS 6 ONERA The French Aerospace Lab. *Paper Number: 9909-174.*

Author contact: jmilli@eso.org