

Amplitude Calibration of Adaptive Optics Supported Solar Speckle Imaging

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Abstract: Adaptive optics supported solar speckle imaging requires calibration of the reconstruction's Fourier amplitudes with the transfer function of atmosphere and optics. We propose analytical models for relevant transfer functions of arbitrarily correcting adaptive optics systems.

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1 Introduction

To study in detail the surface of the Sun, observations with very high spatial resolution are needed. Solar adaptive optics (AO) was developed during the past six years and has become an essential tool for high resolution solar observations. Several solar telescopes operate AO systems on a regular basis with great success.

However, the residual errors of the compensation are sufficiently large to affect the image noticeably most of the time. Therefore, post processing with image reconstruction techniques remains necessary to reach the diffraction limit for a large fraction of observing time. Speckle interferometry is the process of using multiple images of the same object in order to estimate an image of the object that is not distorted by the atmosphere.

This is achieved within two steps. The first step involves the estimation of the object's Fourier phase by computing average cross- or bispectra [3, 5], which are capable to retain Fourier phase signals (as opposed to power spectra). The second step involves the reconstruction of the object's Fourier amplitudes. Simultaneous observations of a nearby, unresolved star usually suffice as tool for calibration. However, in case of solar observations, there is a need to describe the optical system of atmosphere, telescope and AO in form of transfer functions, specifically long exposure (LTF) and speckle transfer functions (STF). The LTF characterizes the transfer function of an exposure that was integrated over an interval much longer than the correlation time of the atmosphere. The STF, on the other hand, characterizes the transfer function of an average short exposure image, i.e., an image integrated over an interval shorter than the correlation time of the atmospheric turbulence. The STF is of specific importance for speckle interferometry. Both transfer functions depend on the atmospheric conditions present at the time of observations.

To this date, efforts have been made to analytically model LTF [1], and STF without AO [4]. The first model to introduce a correction of an AO system included only a complete correction of the first few dozen Zernike modes [7]. No analytical models of STFs including AO systems have been presented up to this point.

We present a straight forward analytical model for the LTF and STF of an arbitrarily correcting AO system by introducing a set of parameters describing its compensation performance. These transfer functions can be computed for any AO system once its performance is well known.

2 Model

We define the transmission of the telescope aperture as

$$W(r') = \begin{cases} \frac{1}{2} & \text{if } |r'| \leq D/2 \\ 0 & \text{if } |r'| > D/2 \end{cases}, \quad (1)$$

which represents a real function. Thus, influences on the incoming wavefront due to atmospheric turbulence (or static aberrations) are described by a separate term $\varphi(r')$. This term can be decomposed into Zernike polynomials $F_i(r')$:

$$\varphi(r') = \sum_{i=2}^{\infty} a_i F_i(r'), \quad (2)$$

where i is the mode ordering number of Zernike polynomials according to Noll [6], and a_i is the coefficient of atmospheric turbulence for a given Fried parameter of the i -th Zernike polynomial. In case an AO is used, $\varphi(r')$

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