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Optically sensitive Medipix2 detector for adaptive optics wavefront sensing

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Abstract

A new hybrid optical detector is described that has many of the attributes desired for the next generation adaptive optics (AO) wavefront sensors. The detector consists of a proximity focused microchannel plate (MCP) read out by multi-pixel application specific integrated circuit (ASIC) chips developed at CERN (“Medipix2”) with individual pixels that amplify, discriminate and count input events. The detector has 256×256 pixels, zero readout noise (photon counting), can be read out at 1 kHz frame rates and is abutable on 3 sides. The Medipix2 readout chips can be electronically shuttered down to a temporal window of a few microseconds with an accuracy of 10 ns. When used in a Shack–Hartmann style wavefront sensor, a detector with 4 Medipix chips should be able to centroid approximately 5000 spots using 7×7 pixel sub-apertures resulting in very linear, off-null error correction terms. The quantum efficiency depends on the optical photocathode chosen for the bandpass of interest.

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Keywords: Adaptive optics; Wavefront sensors; MCP; Medipix; GaAs photocathodes

1. Introduction

Ground-based astronomy in the optical and infrared has the distinct *dis*advantage of observing through the atmosphere. Though mostly transparent over much of the bandpass, the atmosphere is a constantly changing and dynamic medium. The index of refraction of air is a function of density and temperature and the vertical spatial profile of these parameters change with time due to wind-shear induced turbulence. Hence, a plane wave of light from a distant star will be distorted across the constant phase wavefront, leading to blurry images in the focal plane of a telescope or twinkling stars to the human eye.

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Ideally, the angular resolution of a telescope would be limited only by the diffraction limit of the primary mirror, which improves linearly with diameter. The typical ~1 arc second blurring caused by the atmosphere corresponds to the diffraction limit of a 20 cm diameter mirror in the optical bandpass. Therefore, making a ground-based telescope larger than 20 cm does not improve its angular resolution (though it does improve its light gathering power). Space-based telescopes, like the Hubble Space Telescope, do not suffer from atmospheric distortion, but they are expensive to build, launch and operate, and therefore difficult to make much larger.

In the past two decades, techniques have been developed to remove the effects of the atmosphere on the light from distant sources. Adaptive optics is the method of using fast deformable mirrors [1] to conjugate and therefore cancel any phase errors introduced in the light path between the object of interest and its image at the focal plane (Fig. 1). Before correcting the phase of the light, it must be measured using a wavefront sensor that samples the wavefront across the pupil. One method (among many) is the Shack–Hartmann sensor [1] (Fig. 2). The wavefront is sampled by a lenslet array creating individual images focused on an imaging array. If the light is perfectly collimated (e.g. a plane wave from a distant star), the images would be spots of light at the regular spacing of the lenslet array. If the plane wave is distorted, the centroids of the spots would spatially shift depending on the local slope of the wavefront. By measuring the centroids of these spots in real time, one can determine the wavefront error and feed this error signal back to the deformable mirror to "close the loop" and correct all time variable wavefront distortions.

Each centroid determination measures the slope of the constant phase wavefront at that particular location on the wavefront at that particular time. Larger telescopes with larger pupils use deformable mirrors with more actuators and hence more phase measurements, therefore, requiring detectors with many pixels. The atmosphere's variability on most nights necessitates wavefront sampling rates on the order of 100–1000 Hz. The number of photons from the guide stars used as the reference beacon are almost always limited in

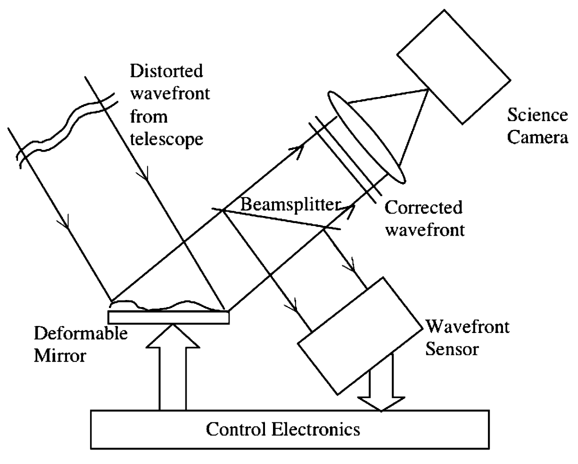

Fig. 1. Simple schematic of an adaptive optics system where the aberrated wavefront is reflected off the deformable mirror resulting in a corrected diffraction limited wavefront passed on to a downstream camera. The beamsplitter takes a sample of the corrected wavefront to monitor the phase and send updates to the control electronics to "close the loop" to the deformable mirror.

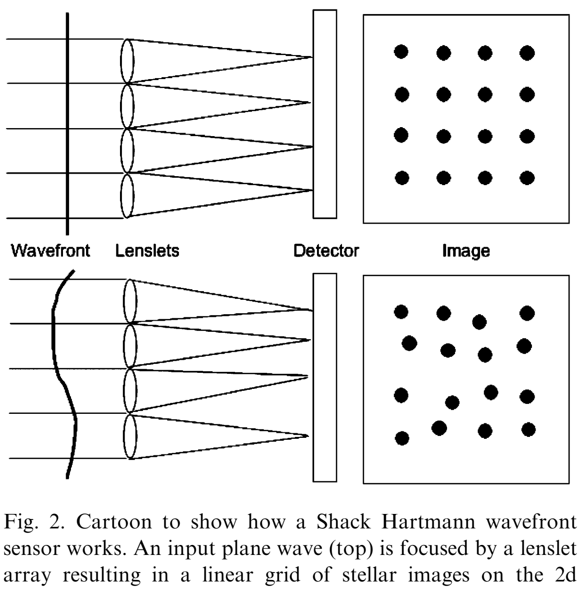

Fig. 2. Cartoon to show how a Shack Hartmann wavefront sensor works. An input plane wave (top) is focused by a lenslet array resulting in a linear grid of stellar images on the 2d detector. If the wavefront is aberrated (bottom), the centroids of the stellar image move away from the original grid. The amount of movement is a function of the slope of the wavefront; hence a Shack-Hartmann wavefront sensor measures the first derivative of the phase of the wavefront.