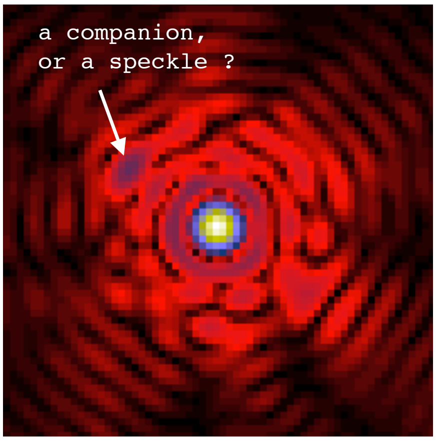
Hard Core Optical Engineering for Astrophysics

Telescope is what most astronomers use to do their science, and it is the image quality of a telescope that ultimately sets the science that can actually be done. All the new and extraordinary observation techniques that are developed today are trying to reach one goal : getting the most of what a telescope can give. In other words, the limit, in astrophysics, is not set by the skills of the scientist, but by the instrument. So, the main advances in astrophysics, today, are done by people who understand the limits and the instruments, ***and*** *are able to push them further by inventing new techniques (adaptive optics, interferometry, stellar coronagraphs, etc.) In this METEOR module, we will explore the main limit of any astronomical instrument - the instrumental static aberrations - and describe ways to minimize them, using what we call phase diversity, in order to reach the ultimate performance of astronomical telescopes and instruments (ground or space based). Controlling the aberrations of an optical system is the key to a successful science observation.*

Astronomical instruments are complex systems, generally made of a few dozen of optical surfaces (mirrors, lenses, filers etc.) and each of these surfaces are sources of small wavefront errors, which, summed up in the focal (or detector) plane, can potentially destroy the image quality, and make the observation impossible. Of course, the components required quality is studied during system's design, and specifications are set for each components of the system, but nothing can make it certain that no unexpected aberrations will still be present in the focal plane, because of manufacture errors, or bad design.

This happens sometime in astronomical instruments. Beside, it is not always possible to design a system to an arbitrary level of image quality simply because of cost. It would be very expensive for instance to develop a system with say 10 nm RMS wavefront error across a system made of 20 optical surfaces - which is not a lot. Therefore, for a given budget, there is always a limit to the optical quality one can achieve.

This is where post design aberrations control techniques play an important role. We need a mean to measure these aberrations, from the point-of-view of the science detector. A way is to capture part of the science light and send it to a wavefront sensor, measure the aberrations, and use this information to control a wavefront correction device upstream the science detector, for instance a deformable mirror. This is what is done in adaptive optics (AO) to compensate most of the aberrations generated by turbulence, which is **by far** the main part of instrumental error for a ground based instrument. And the static aberrations inside the main optical path are therefore also corrected.



Unfortunately an AO system has also its own static optical aberrations, which are not common to the science path. Therefore, if the required image quality is particularly high (for instance in the case of coronagraphs made for exoplanets detection), another, independent way of measuring the global static aberration from the detector plane is required, and for this we use what is called *phase diversity*.

Phase diversity is a numerical technique that seeks to extract the wavefront information directly from point source images. It is based on mathematical inversion techniques, which consider the best possible wavefront solution knowing the image structure and the presence of noise in the images. It has been developed by several groups in the world, and our team has been using, for the Keck Observatory, a method developed by ONERA (Office National d'Etude et de Recherche Aérospatiale, France), which is able to retrieve the wavefront from AO-corrected images of structured objects. This technique allows in principle to send the static wavefront measurement to the AO deformable mirror for correction, on top of the turbulence correction.

In this METEOR module, we will (1) review the basic theory of aberrations in optics, using the Zernike polynomials basis; (2) review the wavefront measurement techniques; (3) run laboratory experiment of phase diversity and classical wavefront sensing. At the end, the student will be able to understand the limits of a real instrumentation, and imagine ways of mitigating their effect (our laboratory is at the Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud, Yverdon-les-Bains, Switzerland).

See also

Phase diversity for Keck telescopes - (enter keyword "phase diversity" in the title/abstract words box)

Contact

☎ +41 78 811 9063 (L. Jolissaint)
✉ laurent.jolissaint@heig-vd.ch