SPECIAL CONTRIBUTIONS

Progress in Adaptive Optics for Astronomy

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The problem of optical distortion produced by the earth's atmosphere has been known in astronomy since Isaac Newton. In 1953 H. W. Babcock (1953) proposed in his paper "The Possibility of Compensating Astronomical Seeing" to use a deformable optical element driven by a wavefront sensor to correct the distortions induced by the atmosphere that affect astronomical imaging. It took another 20 years for this principle to be demonstrated successfully for defence related laser applications. And only in the early eighties the first astronomical adaptive optics projects had been triggered.

Since the last IAU General Assembly in 1988 significant progress has been achieved in this field. At that time, several projects have been on the way, but the demonstration of the feasibility and gain which can be obtained with adaptive optics in (Merkle 1991) high resolution imaging for astronomy was still missing. Meanwhile, one group has demonstrated the feasibility and the potential power of this technique and several other groups are just at the advent of going with their instrumentation to the telescopes.

In 1989, the so-called COME-ON system demonstrated for the first time diffraction limited imaging with adaptive optics in the near IR for wavelengths between 2.2 and 4.8 μm at the Obeservatoire de Haute Provence 1.52-m telescope (Rousset et al. 1989; Merkle et al. 1990) and later, in 1990, at the ESO 3.6-m telescope (Rigaut et al. 1991a). Since then this system, which has developed in a collaboration between the European Southern Observatory and the Observatoire de Paris-Meudon, ONERA, and the company Laserdot in France has been already offered twice to visiting astronomers for purely scientific observing runs.

The COME-ON system is based on a Shack-Hartmann wavefront sensor with 5 by 5 suapertures for the wavefront measurement, a continuous faceplate deformable mirror with 19 piezoelectric actuators, and a controller incorporating a dedicated computer to close the feedback loop. In its early operation, the system had a band-

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width of 10 Hz which was later the increased to 25 Hz (Rigaut et al. 1991a). The system applies the polychromatic approach by sensing the wavefront at visible wavelengths and corrects the infrared imaging. The sensitivity of the wavefront sensor has been drastically improved by the application of an electron bombarded CCD (EBCCD) which is photon noise limited. The limiting magnitude in the visible for wavefront sensing at the 3.6-m telescope is currently $m_R = 11.5$. In addition, an near infrared wavefront sensor has been successfully tested (Rigaut et al. 1991b). A coronograph option is available. This system which is a demonstration prototype and test bench for the large adaptive optics systems for the ESO Very Large Telescope (VLT) (Merkle & Hubin 1991) delivered already scientifically important diffraction limited observations in the near infrared for objects like η CAR, NGC 1068, Ceres, and others. Currently, it is upgraded with a 52 actuator mirror, a 7 by 7 subaperture wavefront sensor, and a modified controller for 35 to 40 Hz bandwidth.

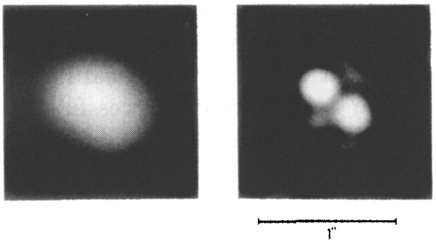

Figure 1: Improvement in image quality with adaptive optics. Diffraction limited imaging of the binary star HR 6658 with 0.38 arcsec separation at 3.8 μm wavelength without any a posteriori data processing (ESO 3.6-m telescope). Left: uncorrected image; right: corrected image.

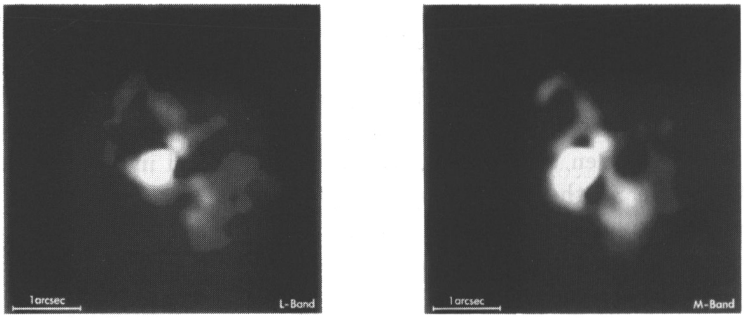

Figure 2: First diffraction limited images of η CAR at 3.5 (left) and 4.8 μm (right); (North is down East is right).

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The adaptive optics project of the University of Hawaii, USA (Roddier 1991) is now working in the laboratory state and will go to the telescope in the fourth quarter of 1991. This system, based on curvature sensing instead of classical wavefront sensing and a bimorph mirror will be operated at visible wavelengths. This approach seems to be a low cost alternative for systems with less than approximately 50 modes of correction.

An other concept has been applied by the Steward Observatory, Tucson in collaboration with the Thermo Electron Corporation, USA (Angel et al. 1991; Sandler et al. 1991) by using neural networks to determine directly from the image information the correction values for the correcting mirror. First tests at the Multiple Mirror Telescope (MMT) demonstrated the feasibility of this method by phasing some of the mirrors.

The Martini system of Durham University, GB is meanwhile in regular use. It allows the coalignment of six smaller circular subapertures by masking the 4.2-m WHT on La Palma. The tilt of each subaperture is corrected to produce sharpen images.

An other test at an astronomical telescope took place at the Yunnan Observatory with an adaptive optics system developed at the Institute of Optics and Electronics, Chengdu China. This system was not specifically designed for the astronomical applications and thus suffers under severe sensitivity problems. Some results for very bright objects are expected in the future.

At Johns Hopkins University, USA the construction of the coronograph with adaptive optics is progressing. This system will apply an electrostatically actuated membrane mirror.

The University of Illinois, USA is committed to build an adaptive optics system for the 3.5-m ARC telescope. A lateral-shearing interferometer as wavefront sensor and several deformable mirrors are under construction. It is foreseen to equip this system with an artificial guide star option.

A 19-segment adaptive mirror system is currently used on the Sacramento Peak 76-cm Solar Tower Telescope in collaboration with Lockheed, USA (Acton & Smithson 1991). This system has proven itself to be capable of substantially improving the image quality. Even under 1 to 3 arcsecond seeing conditions 1/3 of an arsecond resolution has been achieved.

A quit significant input to adaptive optics came in May 1991 from two American groups working on defence oriented applications, the MIT Lincoln Laboratory (Primmerman et al.1991) and the Philips Laboratory in Albuquerque (Fugate et al.1991). Both teams made experiments public which demonstrated that the principle of artificial reference stars for wavefront sensing works, which then will allow to apply adaptive optics with full sky coverage from the infrared wavelengths range down to the visible. Partially, these tests already date back to 1983, two years before this concept had been proposed (Foy & Labeyrie 1985) and first feasibility assessments performed (Thompson & Gardner 1987). The above mentioned results gave a boost to the guide star developments for astronomy and it is obvious that the major very large telescope projects, like the Gemini, the ESO-VLT and others will include this technique in their adaptive optics programs.

During the last three years, it has been demonstrated that adaptive optics is feasible, that it is a useful technique to do astronomy and science. New technologies will make it even more powerful in the future and very likely it will be applicable to a wide range of high resolution imaging problems from the ground and in particular for optical and infrared long baseline interferometry. All major large telescope projects look into the possibilities of implementing adaptive optics in their concept or adaptive optics is even an integral part of their design.

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