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PERFORMANCE OF ADAPTIVE OPTICS IN GROUND-BASED VERY LARGE TELESCOPES: APPLICATIONS TO BROWN DWARF RESEARCH

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RESUMEN

Presento una breve revisión de resultados científicos obtenidos con sistemas de óptica adaptativa en grandes telescopios situados en el observatorio de Mauna Kea (Hawaii), con especial atención al estudio de las enanas marrones. Usando datos reales obtenidos por el autor, se muestra una comparación entre dos sistemas de óptica adaptativa que utilizan dos técnicas diferentes para medir las deformaciones del frente de onda (curvatura y Shack–Hartmann), y se discuten las ventajas de cada uno.

ABSTRACT

I briefly review some scientific results obtained using adaptive optics systems in very large telescopes at Mauna Kea observatory (Hawaii), with particular emphasis on research on brown dwarfs. The performance of two different adaptive optics systems are compared using real data obtained by the author. I discuss the advantages and disadvantages of Shack–Hartmann sensing (Keck facility) versus wavefront sensing (Hokupa'a on Gemini).

Key Words: **STARS: EVOLUTION — STARS: VERY LOW MASS, BROWN DWARFS**

1. INTRODUCTION

It is well known that the point spread function (PSF) delivered by ground-based very large telescopes without adaptive optics is degraded by atmospheric blurring (seeing). Even on superb nights at good sites such as Mauna Kea, La Palma, or Paranal, seeing is about FWHM =0.2 arcsec at best in the near-infrared. However, the diffraction limit of a 10 m telescope in the K band is 0.046 arcsec. Thus, adaptive optics (AO hereafter) can improve the image quality of very large ground-based telescopes by about a factor of 40 in the near-infrared, and by even more in the optical.

There are four AO systems currently in operation atop Mauna Kea observatory on Big Island (Hawaii). Pueo at the Canada–France–Hawaii Telescope (CFHT) is a 19-element curvature system that has been used since 1996. Hokupa'a was built at the Institute for Astronomy, University of Hawaii, and has been a visitor instrument of Gemini-North from 1999 to 2002. It is a 36-element curvature system. It will soon be replaced by the Altair system, which is based on Shack–Hartmann sensors. The Keck observatory has an AO facility that uses a 349-element deformable mirror and Shack–Hartmann sensors. The Subaru Telescope has an AO system that is basically a copy of Hokupa'a.

2. A SELECTION OF SCIENTIFIC RESULTS

In this paper, I have focused on results obtained using AO systems in Mauna Kea that are of relevance to the topic of brown dwarfs. Other AO results include studies of Solar System bodies (for example binary Kuiper Belt objects), the Galactic Center, and active galactic nuclei.

AO systems increase the dynamical range of astronomical observations because the light is more spatially concentrated. Hence, it is possible to detect faint objects close to bright sources. Two brown dwarf companions to solar-type stars have recently being reported (Liu et al. 2002; Potter et al. 2002). Both were first detected with Hokupa'a on Gemini, and follow-up spectroscopy was secured with Keck + NIRSPEC-AO. Since the number of solar-type stars observed with AO systems in very large ground-based telescopes is still small (< 50), these two companions suggest that brown dwarfs may be relatively common around stars at separations greater than 10 AU. On the other hand, it is well known that brown dwarfs are rare within 5 AU of solar-type stars (Vogt et al. 2002). A dependency of the frequency of brown dwarf companions on orbital separation from the star is explained by some models of orbital migration in circumstellar disks.

The high spatial resolution provided by AO allows close binaries to be resolved. Ultracool dwarfs can be observed with conventional AO systems if they have a bright star within about 30 arcmin, but Hokupa'a has demonstrated that the brightest dwarfs can be observed directly. Several tight binaries have been discovered (Martín et al. 2000; Close

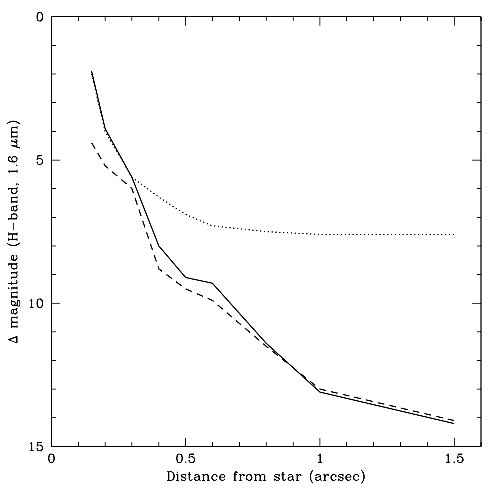

Fig. 1. Comparison of contrast sensitivities for two AO systems. Solid line: 5 sigma, 5 min, Gemini/Hokupa'a, $V = 7$, G2 V; Dotted line: 5 sigma, 30 min, Gemini/Hokupa'a, $I = 13$, M6 V; Dashed line: 5 sigma, 5 min, Keck/AO, $V = 6$, G2 V.

et al. 2002). All of them have separations between 1 and 15 AU. The tighest of them has been followed up with Keck + AO and an orbit has been derived by Lane et al. (2001). These are the first dynamical masses for brown dwarfs.

3. COMPARISON BETWEEN TWO DIFFERENT AO SYSTEMS

It is likely that the GTC will in the future pursue the development of an AO facility. It will be useful for the GTC to learn from the AO experiences of other observatories.

The AO system performance is usually determined by the wavefront sensor. The goal of any AO system is to flatten the wavefront. For this purpose the wavefront distortion is measured on a very short timescale (about 1 ms). Two ways of measuring the wavefront signals have been implemented in major observatories: curvature and Shack–Hartmann. The first one images the source in two planes, one before the focus and the other beyond the focal plane. The intensities of both images are reversed with respect to each other. The AO system modifies the deformable mirror to make the intensities equal on both sides of the focus. The second kind of AO sensing makes an array of images using a lenslet array.

The Gemini and Keck observatories have chosen the Shack–Hartmann technique for the facility AO instruments. Note, however, that the curvature system Hokupa'a has been a visitor instrument at Gemini for three years. The Subaru telescope has opted for a curvature system similar to Hokupa'a.

So far, I have observed and analyzed data obtained with Keck/AO and Hokupa'a on Gemini. The diffraction limit of the telescope has been reached in some images obtained with Keck, but not with Hokupa'a. It is thought that an 85-element curvature system is required to reach the diffraction limit with curvature AO in an 8 m telescope. The Institute for Astronomy is currently building one such system for Gemini.

In Figure 1 I present some AO results in terms of contrast between a bright star and a faint companion. The advantage of the curvature system is that it allows us to work at almost the diffraction limit with relatively faint natural guide stars. The disadvantage is that for bright stars the images are less sharp and the contrast is smaller than for the Shack–Hartmann AO system.

4. CONCLUSIONS

AO systems are becoming standard equipment in very large ground-based telescopes such as Gemini, Keck and Subaru. The sharp images delivered by AO can be used to resolve tight brown dwarf binaries, and to detect substellar companions to nearby stars. The first discoveries of these objects in small samples of targets are very encouraging. Two main types of AO wavefront sensing have been implemented; curvature and Shack-Hartmann. While the curvature system allows to guide on fainter stars, such as nearby ultracool dwarfs, the Shack-Hartmann delivers sharper images for bright stars.

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