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HIGH CONTRAST IMAGING WITH THE MAGELLAN VisAO CAMERA

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Abstract. The Magellan Adaptive Optics system (MagAO) saw first light in November 2012 at Las Campanas Observatory on the 6.5m Clay telescope. Here we present an introduction to MagAO's visible wavelength diffraction limited imager, VisAO. VisAO delivers Strehl ratios greater than 30% from 0.62 microns (r') through 1 micron, where Strehl is even higher, and achieved resolutions as small as 20 milli-arcseconds. There are several design considerations which allow VisAO to achieve such good performance on a large telescope, and these will have important implications for ELT AO systems. We took advantage of the excellent performance of MagAO/VisAO to conduct high contrast observations of an exoplanet in the optical.

1 Introduction

The Magellan Adaptive Optics system (MagAO) combines a 585-actuator adaptive secondary mirror (ASM) and 28 × 28 pyramid wavefront sensor (PWFS). It is a near-clone of the highly successful Large Binocular Telescope (LBT) AO systems [1,2]. MagAO is installed on the 6.5 m Magellan Clay Telescope at Las Campanas Observatory (LCO), in Chile. MagAO is shown mounted on Clay in Figure 1. The system saw first light in December, 2012, and underwent a second commissioning run in April and May, 2013. These commissioning runs have resulted in several scientific publications [3–5], with several more currently in preparation. See also [6] in these proceedings.

A key component of MagAO is its visible-wavelength diffraction-limited imager, VisAO. This science camera is co-mounted on the PWFS optical board, and is essentially an upgrade of the LBTAO baseline technical viewer. In Figure 2 we show the co-mounted PWFS and VisAO camera, collectively called the "W-Unit". The VisAO detector is an e2v CCD 47 with SciMeasure "Little Joe" electronics. VisAO includes a filter wheel with standard SDSS r', i', and z' bandpasses, as well as a filter we call "Y-short", or Y_S, with a central wavelength of 0.985μm. A second filter wheel contains custom narrow-band filters for use with a Wollaston beamsplitter, an ND 3 filter, and an anti-blooming occulting mask. A motorized stage allows focusing the

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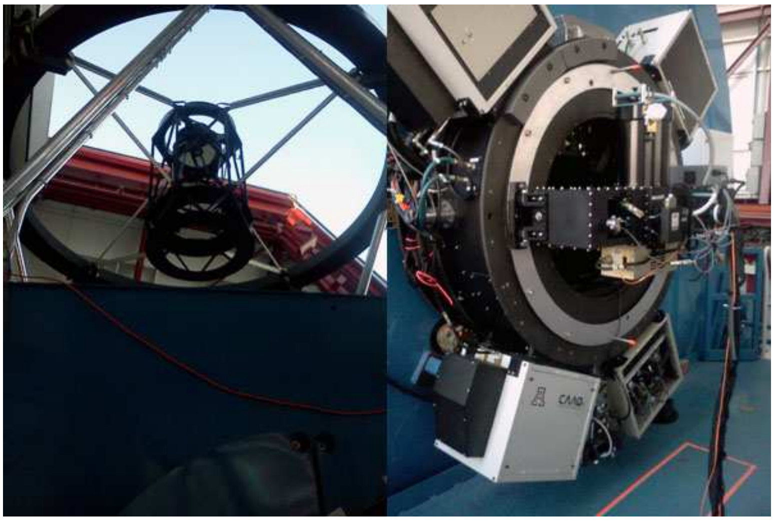

Fig. 1. The MagAO system installed on the 6.5 m Clay Telescope at LCO. At left we show the 585-actuator ASM. At right is the “NAS” unit, which contains the W-Unit (PWFS+VisAO) and Clio2 IR science camera.

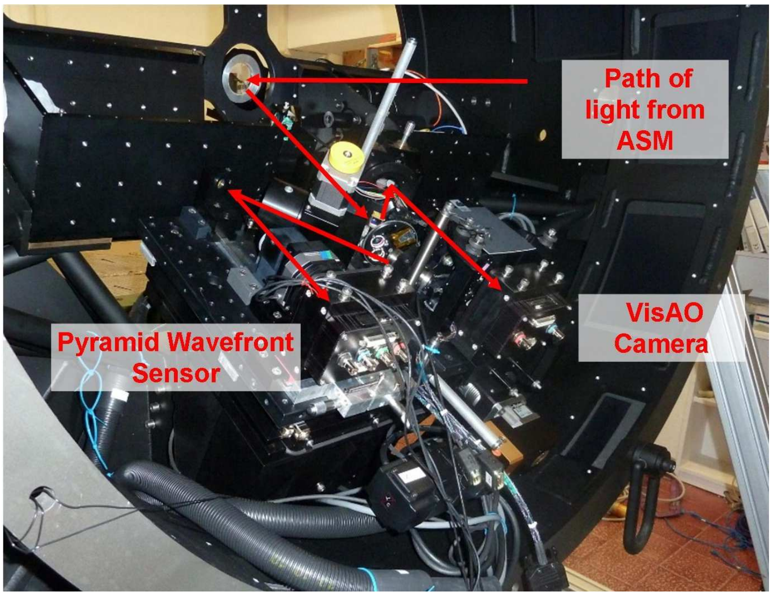

Fig. 2. The “W-Unit”, which contains the co-mounted PWFS and VisAO science camera. Light from the telescope tertiary first encounters the Clio2 (IR science camera) entrance window. This is a dichroic, which sends the $\lambda \lesssim 1.05\mu$m light into the W-Unit. From there, a selectable beamsplitter controls how light is shared between the PWFS and VisAO.

VisAO CCD relative to the PWFS, and a motorized gimbal mirror steers the beam on the CCD. Here we briefly describe the performance of VisAO as a high-contrast exoplanet imager.

2 VisAO On-sky Performance

We observed the known exoplanet host star β Pictoris in December 2012. We show our measured point spread function (PSF) in Figure 3. Using the unsaturated, un-occulted PSF and employing several techniques we measured a focal plane Strehl ratio (SR) of 32 ± 2%. The CCD suffers from non-negligible charge-diffusion, and the resulting pixel-response function (PRF), which we measured in the lab, lowers measured SR by a factor 0.8. This means that our true SR was 40% in Y_S at 0.985μm.

We observed β Pic for over 4 hours, obtaining 116 degrees of sky-rotation in angular differential imaging (ADI) mode. These observations were conducted in Y_S, using the occulting mask to prevent CCD bleeding. Using PWFS telemetry, we selected the best ~2 hr of this data, and formed a median PSF. This is shown in Figure 3 as well. We applied the KLIP principal component analysis (PCA) algorithm [7]. The resulting ADI+PCA contrast curve is shown in Figure 4, where we compare it to the fundamental limits imposed by halo-photon noise and readout noise.

The exoplanet β Pic b is a ~10 M_{Jup} giant planet on a ~9 AU orbit [8]. We detected β Pic b simultaneously with Clio2 in M' (4.7μm) and with VisAO in Y_S. In Y_S the detection contrast was $\sim 1.8 \times 10^{-5}$ at a separation of ~0.46″, or ~9AU. For more on the VisAO detection of β Pic b see [9], where we use our Y_S photometry in combination with prior measurements to compare this exoplanet to field brown dwarfs. More information on the Clio2 detections is provided in these proceedings [10], and in [11].

3 Conclusion

MagAO's visible wavelength science camera, VisAO, has been demonstrated as a powerful high-contrast imager. VisAO routinely achieves SRs as high as 40% at $\lambda < 1\mu$m. VisAO achieved very good contrast while observing β Pictoris. With advanced image processing techniques we reach the photon noise floor outside ~1″. Using this new capability, we detected the $\sim 10 M_{Jup}$ extrasolar giant planet β Pictoris b at 0.46″ on the VisAO CCD.

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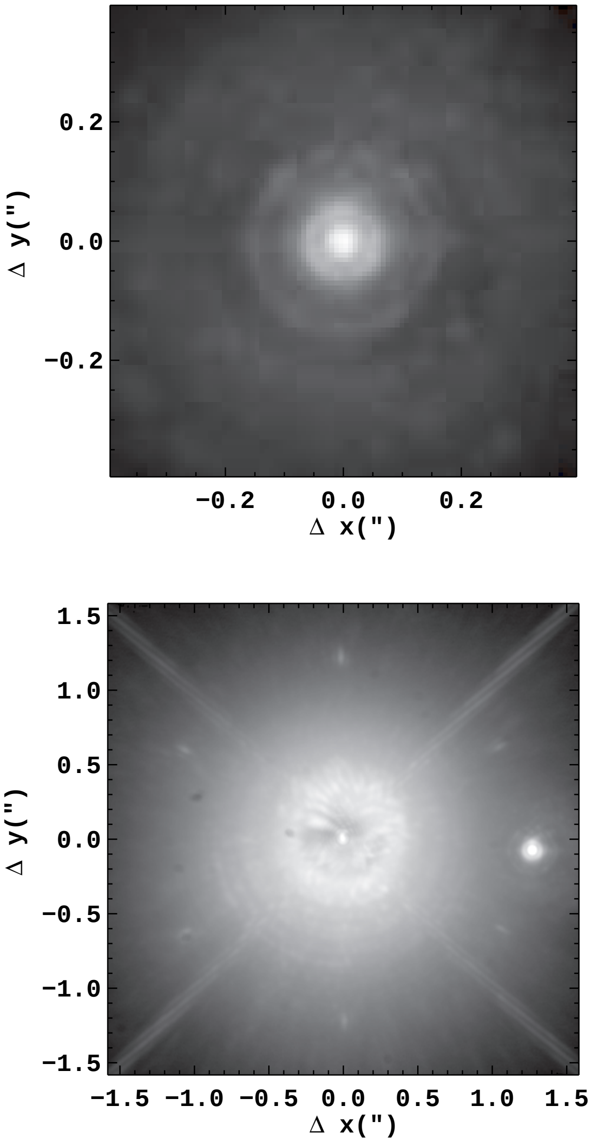

Fig. 3. Top: unsaturated MagAO/VisAO 1μm PSF. The Strehl ratio is 40%. Bottom: Median PSF after 2 hour ADI exposure behind the anti-blooming occulting mask.

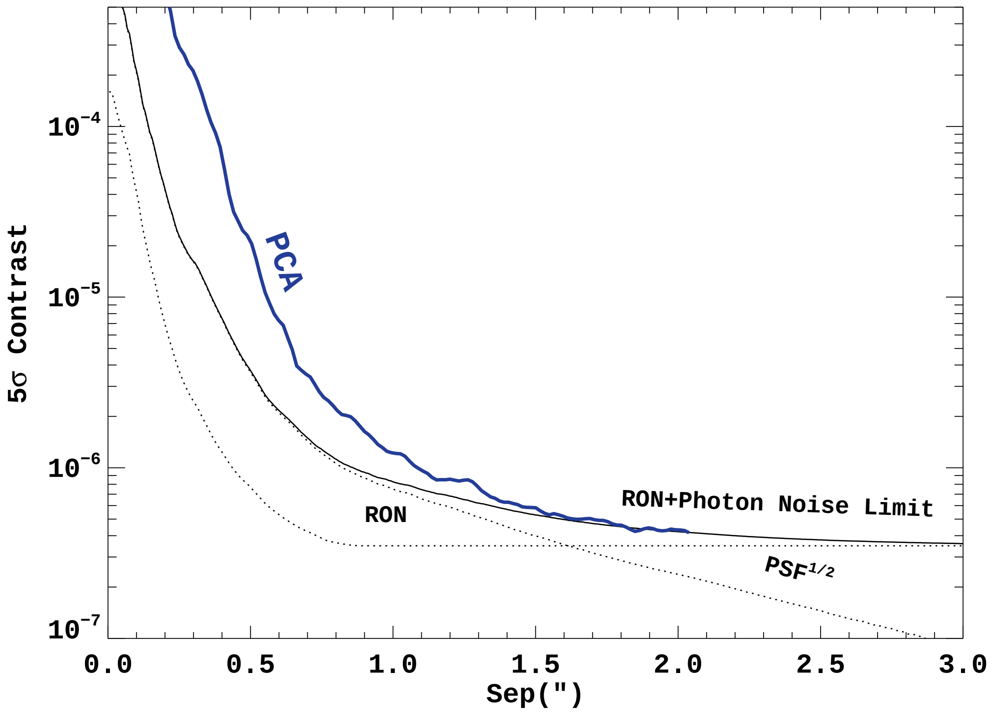

Fig. 4. VisAO contrast curve. Here we show the 5σ contrast limit achieved in a ~2 hr observation of β Pictoris. The blue curve is the result of principal component analysis (PCA) data reduction. We compare it to the limits imposed by photon noise in the PSF halo and readout noise. All curves are corrected for transmission of the occulting mask and ADI and PCA processing throughput.