High Contrast Imaging with Focal Plane Wavefront Sensing and PIAA for Subaru Telescope

Olivier Guyon, Hideki Takami, Eugene Pluzhnik, Shinishiro Tanaka, Basile Gallet, and Stephen Colley
Subaru Telescope

Motohide Tamura and Lyu Abe
National Astronomical Observatory of Japan

ABSTRACT

We describe in this paper the plans for a high contrast imaging system to be deployed on Subaru Telescope. This system makes efficient use of both the new curvature AO systems at Subaru which recently had first light, and the HiCIAO camera, which will be completed in 2007.

The proposed system will use "focal plane wavefront sensing" (FPWFS), a scheme where focal plane images are used to measure the wavefront. It will also use the highly efficient PIAA coronagraph. We show that these choices will result in a highly efficient high-contrast imaging instrument. Key techniques for this project are being demonstrated in our high contrast testbed at Subaru Telescope.

OVERALL DESIGN

The overall design for this project is shown in Figure 1. The proposed system takes full advantage of a very favorable environment for our high contrast imaging project:

– AO188 is a high performance AO system, delivering good quality images with approximately SR=0.5 in H band. It is a very good first stage AO system for our project.

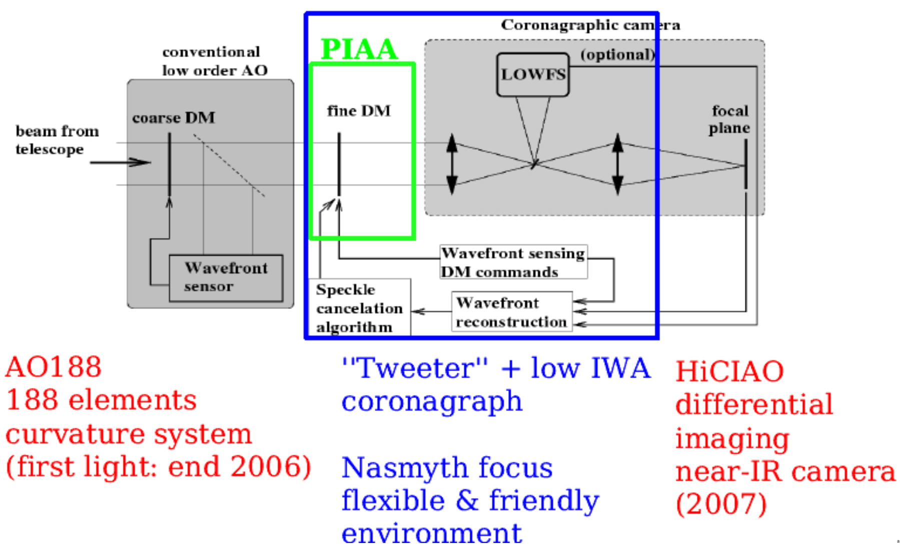

Figure 1: *Block diagram of the high contrast imaging system for Subaru Telescope. Both the AO188 system and HiCIAO are well advanced projects. Our goal is to include between HiCIAO and AO188 a PIAA coronagraph equipped with a deformable mirror (DM).*

– HiCIAO is an imaging camera specifically designed for high contrast coronagraphic imaging. It also offers simultaneous differential imaging around the methane absorption feature in H band. It has been designed to allow new coronagraph systems to be tested, and is therefore very flexible.

– Both HiCIAO and AO188 are at a Nasmyth focus, which offers the space and flexibility to easily deploy new instruments.
– We are acquiring unique experience in PIAA coronagraphy and focal plane wavefront control from our laboratory testbed at Subaru Telescope.

CORONAGRAPH: PHASE-INDUCED AMPLITUDE APODIZATION (PIAA)

Conventional apodization coronagraphs use masks to apodize the telescope pupil. These masks unfortunately remove most of the planet light and greatly reduce the telescope angular resolution.

An alternative solution is to produce the apodized pupil by geometrical redistribution (remapping) of the flux in the pupil plane rather than selective absorption. The PIAAC performs this lossless amplitude apodization with 2 aspheric optics; the resulting pupil is then yields a high contrast PSF in which starlight can be removed by a small focal plane occulting disk.

A schematic representation of the PIAAC is shown in Figure 2, which also shows off-axis PSFs in both the "intermediate" focal plane (where the focal plane occulter is located) and the final focal plane (where field of view is restored).

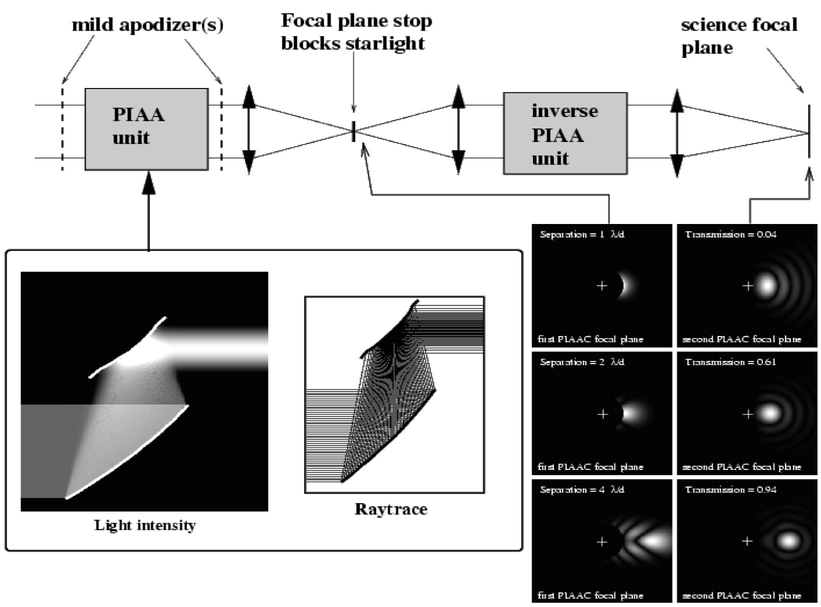

Figure 2: *Schematic representation of the PIAAC. The telescope light beam enters from the left and is first apodized by the PIAA unit. Mild apodizer(s) are used to perform a small part of the apodizations, and are essential to mitigate chromatic diffraction propagation effects and to allow for the design of "friendly" aspheric PIAA microns. An high contrast image is then formed, allowing starlight to be removed by a small occulter. An inverse PIAA unit is required to "sharpen" the image of off-axis sources.*

The PIAAC coronagraph performance is quantified and compared with other coronagraphs in the "Theoretical analysis of coronagraphs" paper in this volume. We summarize here the main characteristics of the coronagraph:

- nearly 100% throughput
- 1 λ/d angular resolution
- ~1 λ/d IWA
- full 360 deg search area
- good achromaticity

In the PIAAC design adopted for this project, the aspheric optics deliver the apodized entrance beam to a Lyot-type coronagraph. While some of the starlight is removed by the focal plane occulter, the Lyot pupil plane mask also contributes to starlight rejection. This design allows a smaller IWA (see Fig. 3) than for the more conventional PIAAC design considered for higher contrast space use (see the paper about PIAAC in this volume).

The PIAAC system optics are also designed to work with the Subaru Telescope pupil central obstruction and spider vanes. First, a **Spider Removal Plate** (SRP) removes the spider vanes from the pupil. This is achieved by translating 4 segments of the pupil closer together—this translation is obtained by a tilt in a transmissive glass plate, and the SRP is therefore a rooftop-shaped plate of constant thickness. The PIAA optics, chosen to be lenses for this design, can then remove the central obstruction while performing the apodization.

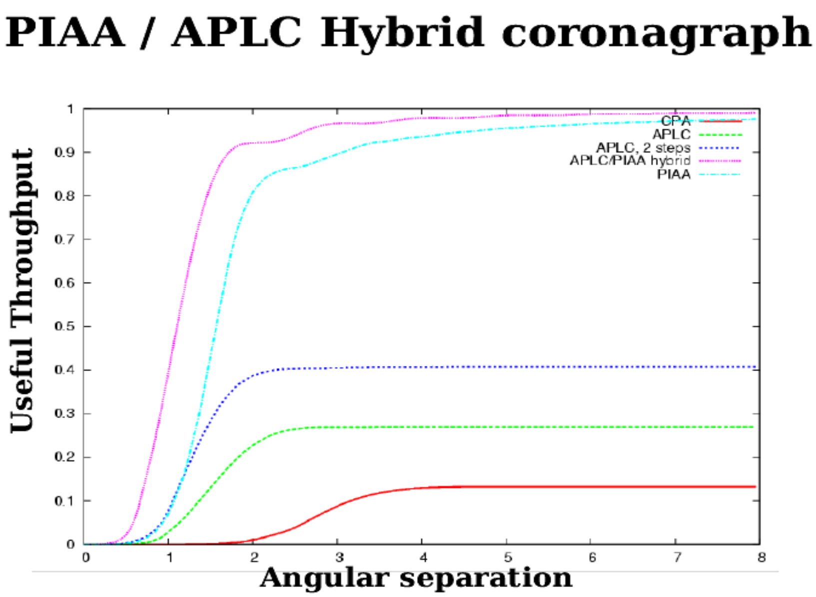

Figure 3: *Comparison between Conventional Pupil Apodization (CPA), Apodized Pupil Lyot Coronagraph (APLC), conventional PIAA (PIAA) and the hybrid solution adopted for the Subaru high contrast imaging system (APLC/PIAA hybrid). The APLC/PIAA hybrid solution offers improved IWA and throughput.*

WAVEFRONT CONTROL

The focal plane images acquired by the science camera (HiCIAO) will be used to estimate the wavefront in a phase-diversity sensing scheme. The DM will be used both to introduce the phase diversity and to correct for the wavefront aberrations. This scheme, which has been used to reach very high contrast on the HCIT bench, is also very attractive for ground-based systems:

- it is optically extremely simple, requiring no dedicated WFS optics
- it is extremely sensitive and makes optimal use of a small number of photons
- by design, it is not prone to non-common path errors
- The sensing wavelength is the same as the science wavelength, thus avoiding wavefront chromaticity effects

We have successfully demonstrated the technique in our laboratory testbed at Subaru Telesope (see Fig. 4).

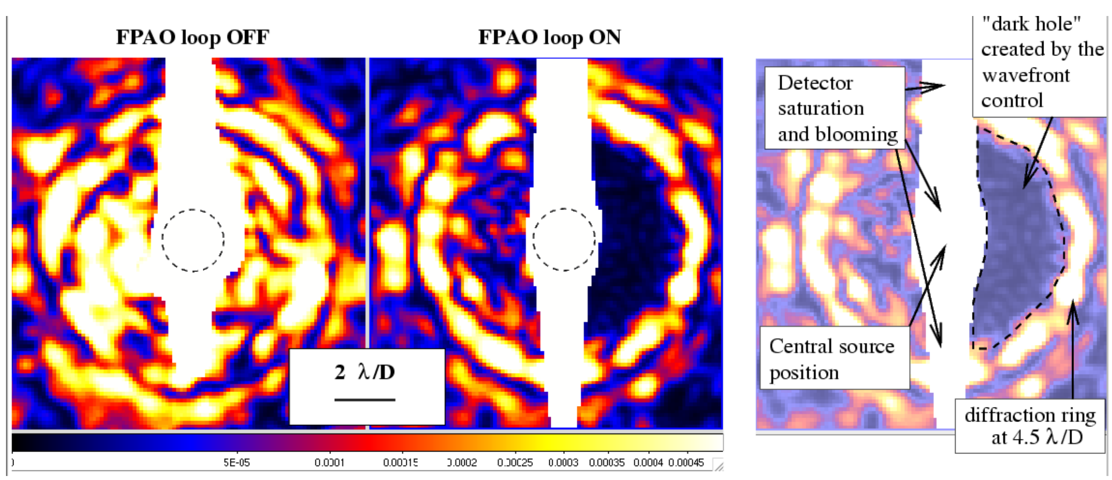

Figure 4: *Preliminary results from the PIAA coronagraph + Focal plane AO laboratory demonstration. A heavily stretched version of our laboratory PSF image (left) shows that almost all starlight is concentrated within 1.5 λ/D radius (the large vertical structure is due to charge bleeding on the detector).*

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