

CIAO: a new way to enhance your ground-based telescope with Adaptive Optics

Guillaume Dovillaire^a, Clément Freslier^a, Luce Razakarivino^a
^aImagine Optic, 18 rue Charles de Gaulle, 91400 Orsay FRANCE

ABSTRACT

Adaptive optics has proved to be an indispensable tool for astronomers observing from the ground. If adaptive optics remains limited today by seeing conditions and the amount of light, the fact is that they are powerful systems and highly demanded by astronomers. However, these systems are expensive and often custom-made for specific telescopes, so only a few can afford them.

CIAO, for Compact Innovative Adaptive Optics, is designed to be interfaced on [0.3 – 1] meter class telescopes, therefore being more easily adaptable and affordable for the astronomical community. The system is based on standard components: a piezo-electric deformable mirror and a Shack-Hartmann wavefront sensor “HASO FAST”. CIAO can be fixed on a telescope through the eyepiece interface and creates a new focal plane on which a camera or a fiber holder can be installed.

The system dedicated to visible light has already been tested in many conditions and on various objects such as planet. or LEO satellites.

Furthermore, its SWIR version running at 3.5kHz is able to optimize the coupling efficiency in a single mode fiber. An mean absolute loss of -7dB has been proven under very strong turbulences condition

Keywords: SSA, Adaptive Optics, Atmospheric turbulences, Lucky imaging, telescope, Satellite tracking

1. CONTEXT

Images acquired through a turbulent atmosphere suffer of a lack of resolution due to wavefront errors created by the inhomogeneity temperature of air in the optical tunnel. In the last 50 years, professional astronomers use adaptive optics to compensate most of the wavefront errors by the use of wavefront sensors and deformable mirrors. More recently, this technique has been improved by prediction algorithms which allow to estimate the coming wavefront and therefore optimize the adaptive optics performances. On the other hand, amateur astronomers use very fast and sensitive cameras to do “lucky imaging”. This technique allows to retrieve diffraction limited images on telescope up to 500mm diameter but only during nights with stable atmosphere.

2. THE CIAO DEVICE

CIAO (Fig.1), for Compact Innovative Adaptive Optics, is designed to be interfaced on [0.3 – 1] meter class telescopes, therefore being more easily adaptable and affordable for the astronomical community. CIAO can be fixed on a telescope through the eyepiece interface and creates a new focal plane on which a camera or a fibre holder can be installed.

A 40 actuators piezoelectric deformable mirror and a 13x13, 1kHz Shack-Hartmann wavefront sensor are the key components of this device.

The adaptive optics closed loop can reach 1kHz frame rate for objects with magnitude lower than 3 on a 600mm diameter telescope.

Thanks to a collaboration with ONERA on the FEELINGS optical ground station, some impressive results have already been obtained (Fig. 1) and a very promising rejection bandwidth has been measured (Fig. 1).

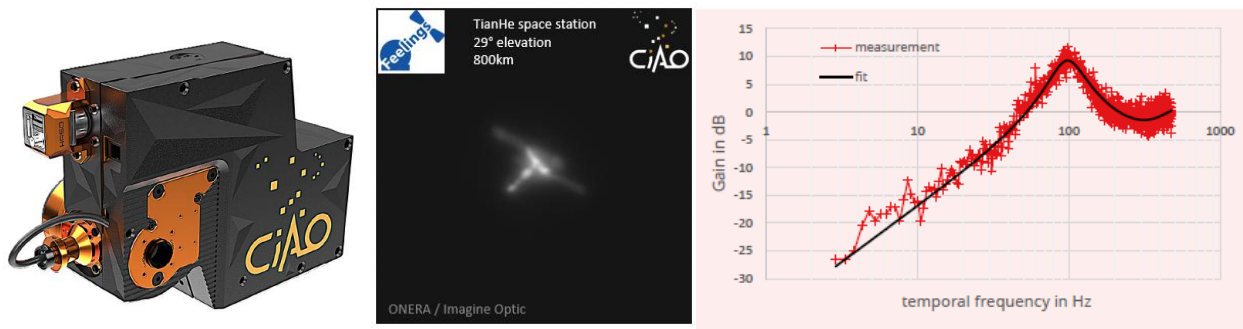


Figure 1. Left, a picture of the device CIAO; center, an AO corrected image of the Chinese space station TianHe; right, a rejection bandwidth measured on sky

3. THE WAVEFRONT SENSOR

The Shack-Hartmann technique (Fig 2.) has been chosen to measure the incoming wavefront due to its robustness and its high level of reliability. A matrix of points is created on the detector; the position of each spot is calculated and the wavefront derivatives obtained.

In very low light condition, the impact of the camera readout noise is very big as the number of photons per microlens per frame can be as low as 25.

We have designed a Shack-Hartmann (microlens focal length and pitch, camera ...) which gives the best compromise between noise for fainter objects, speed and accuracy for brighter ones.

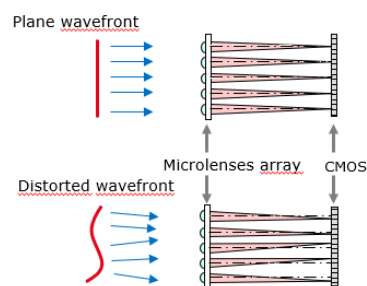


Figure 2. Principle of the Shack-Hartmann wavefront sensor, microlenses array and detector

The Shack-Hartmann wavefront sensor has been designed to allow the measurement on extended sources (fig. 3). A field stop is indeed used to avoid sub-images crosstalk on the detector. A specific algorithm based on images intercorrelation replaces the classical way based on centroid calculation.

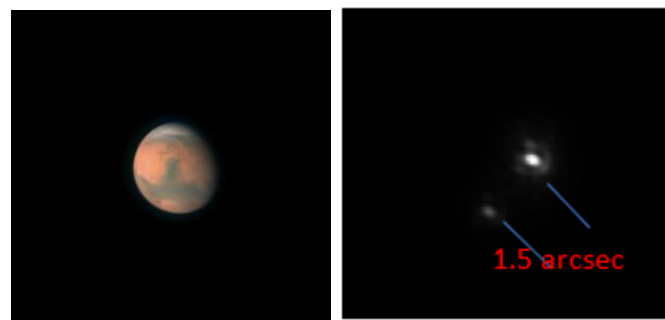


Figure 3. Example of AO corrected images on extended object on the left (planet mars)

4. CIAO SWIR FOR FSO AND SATCOM

Using the same deformable mirror but a wavefront sensor based on a InGaAs detector, we developed a CIAO device dedicated to Free Space Optics and Laser satellite communication. The closed loop can run at 3.5kHz. Instead of an imaging camera, we set a single mode fiber holder at the output port of CIAO.

We tested our device on our atmosphere emulator bench in our facility (Fig.4).

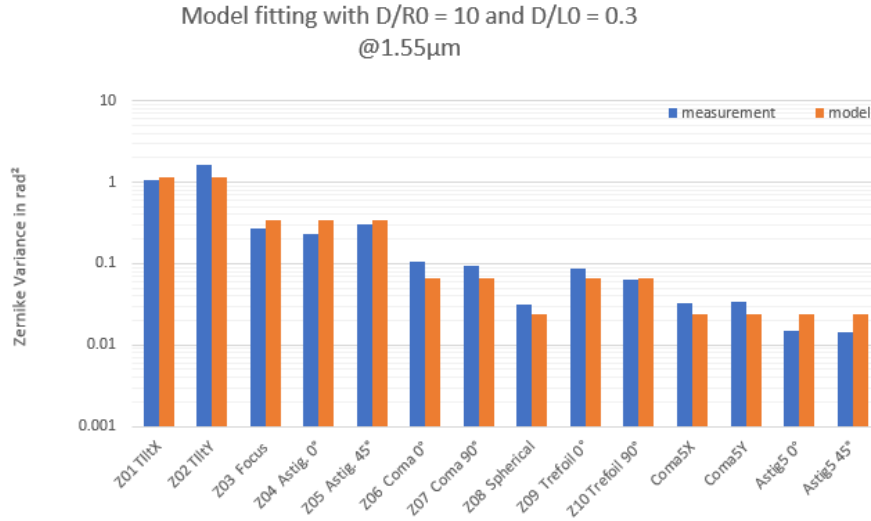


Figure 4. Characterization of our turbulence emulator in SWIR showing very strong turbulence satte of $D/R0 = 10$ @ 1.55 μ m

Using a InGaAs photodiode at the output of the single mode fiber, we measured the flux during time at 34kHz (Fig. 5)

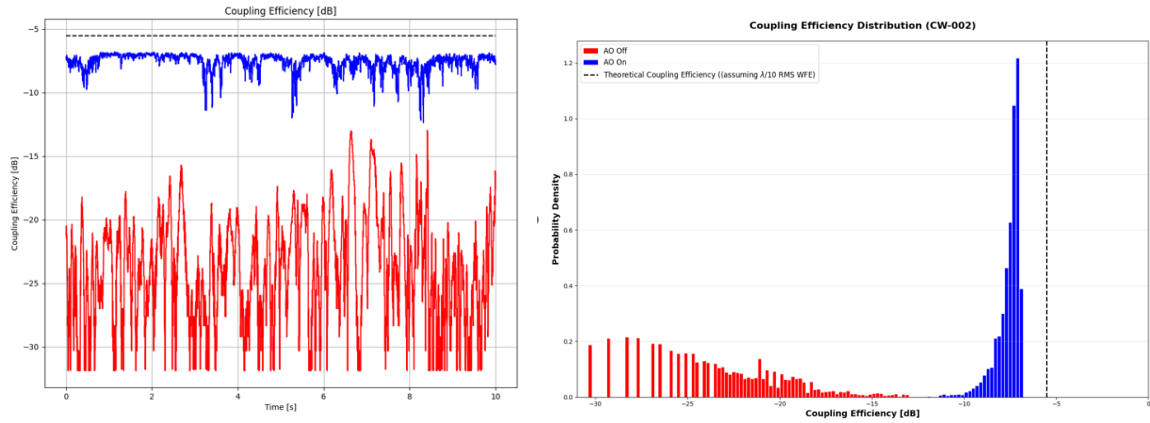


Figure 5. Left, the evolution in time of the AO corrected signal in blue and the open loop in red. Right, the distribution.

The theoretical best coupling efficiency is estimated assuming a wavefront residual of 1/10 RMS and take into account the effect of the aperture diffraction (including a central obscuration) and the internal loss of CIAO.

5. TOWARDS A HIGH-RESOLUTION IMAGER FOR EMISSARY

In the frame of the European Defense Fund EMISSARY project, Ariane Group and Imagine Optic collaborate to develop a high-resolution imager dedicated to Space Situational Awareness (SSA). The Adaptive Optics (AO) system CIAO developed by Imagine Optic is the starting point of an optimization of many characteristics in order to fulfill the specifications of the project. We'll present the high-resolution images of Low Earth Orbit (LEO) satellites that we already acquired with the standard CIAO device and the measurements that will be used to design the future AO system. Our design approach is based on simulations using measured complex field of light.

In order to estimate the acceptable wavefront residual after adaptive optics, we conduct some simulations (Fig 6.) which include the classical technique of lucky imaging (image selection, stacking and contrasts enhancement)

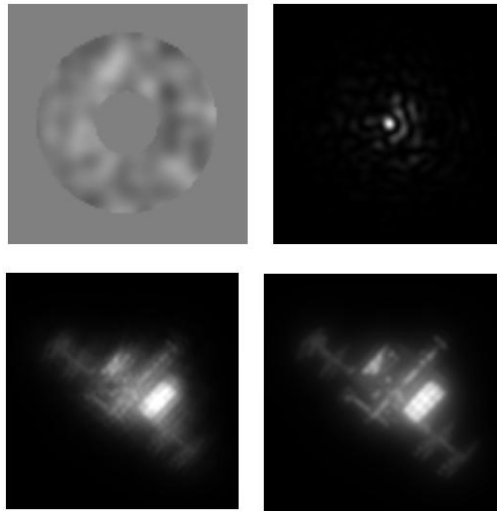


Figure 6. simulated wavefront residual (top left), PSF (top right), simulated raw image of ISS (bottom left), restored image after lucky imaging process. The diffraction limit is reached

In the following months, we'll work on the prediction algorithms, they will definitively improve the level of performance of the imager but we still don't know how. In our knowledge, these approaches have never been implemented on a "small AO system" but only tested on very large telescopes for astronomy.

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