SCExAO

NAOJ - SUBARU Telescope

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SCExAO:

Directly imaging exoplanets with large ground-based telescopes critically relies on high performance cameras to accurately measure atmospheric turbulence and detect the faint planet signal.

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) is a high contrast imaging instrument installed on the **8-m Subaru Telescope** on top of Maunakea, Hawaii.

SCExAO's main goal is the direct imaging of exoplanets, brown dwarf companions, circumstellar dust, and circumstellar environments. The SCExAO project includes the most advanced optical and near-IR camera technologies, and the instrument team collaborates with detector experts to integrate and validate advanced technologies for exoplanet imaging.

SCExAO's unique modular design makes it the ideal instrument to test innovative technologies and algorithms quickly in a laboratory setup and subsequently deploy them on-sky. SCExAO benefits from a first stage of wavefront correction with the facility adaptive optics AO188, and splits the 600-2400 nm spectrum towards a variety of modules, in visible and near infrared, optimized for a large range of science cases. The integral field spectrograph CHARIS, with its J, H or K-band high-resolution mode or its broadband low-resolution mode, makes SCExAO a prime instrument for exoplanet detection and characterization. The newest addition is the 20k-pixel Microwave Kinetic Inductance Detector (MKIDS) Exoplanet Camera (MEC) that will allow for previously unexplored science and technology developments. MEC, coupled with novel photon-counting speckle control, brings SCExAO closer to the final design of future high-contrast instruments optimized for Giant Segmented Mirror Telescopes (GSMTs).

First Light Imaging provides the turnkey high frame rate high sensitivity cameras systems for the instrument, enabling fast and easy integration of some of the most advanced detector technologies. The SCExAO team also works closely with several academic institutions developing new detector technologies (**University of California Santa Barbara, University of Hawaii, Northwestern University**).

OCAM2K:

The extreme adaptive optics correction is performed using a **Pyramid Wavefront Sensor (PyWFS)**, composed of a pyramidal optics that splits the visible PSF into 4 pupil images formed on a First Light Imaging OCAM²K camera. **Thanks to the OCAM²K, SCExAO's PyWFS can run up to 3.6 kHz, which makes it currently the fastest in the world on a 8-m telescope**.

The PyWFS sends commands to a 2000-actuator deformable mirror, to correct residual atmospheric turbulence and other wavefront errors. This extreme adaptive optics loop provides stable high-quality images, with Strehl ratios between 80 and 90%. This step is essential to perform high-contrast imaging and detect faint companions next to a star.

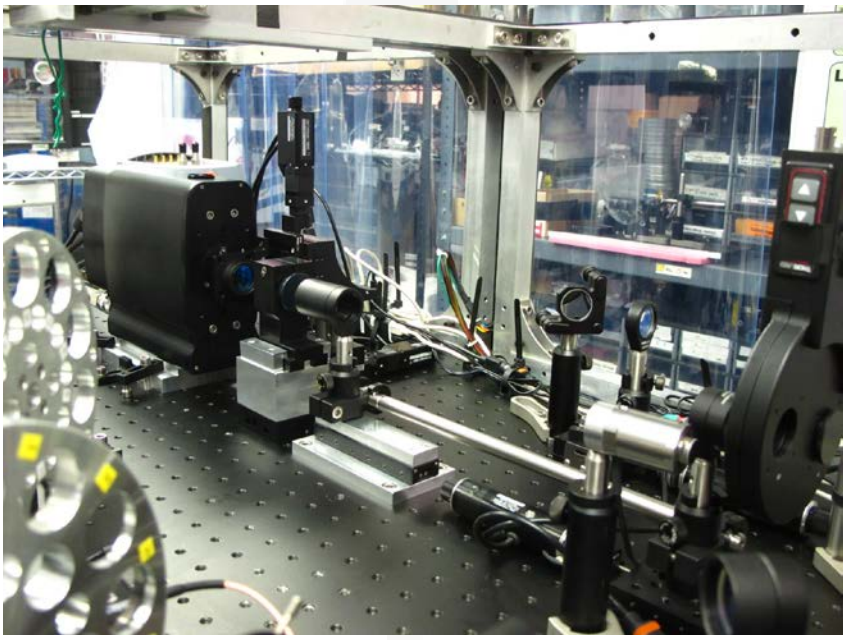

Fig. 1 : OCAM²K – PyWFS (Photo : SCExAO)

C-RED 2 :

SCExAO is constituted of two main parts, a visible part (0.6-0.9 µm) and an infrared part (0.95-2.4 µm).

The infrared part of the instrument possesses a multipurpose internal SWIR camera, recently upgraded to a First Light Imaging C-RED 2 camera.

The C-RED 2 is used for internal alignments of the starlight, in the focal plane and the pupil plane, as well as the coronagraphs used to mask this starlight to reveal fainter companions. The camera also operates as a focal plane wavefront sensor, which can correct either low-order quasi-static errors, or quasi-static speckles, created by aberrations that mimic companions around the central star. Finally, it is also used for controlling the flux injected in single mode fibers, allowing the acquisition of exoplanet spectra using the high-resolution InfraRed Doppler (IRD) spectrograph.

Coronagraphic Low-order wavefront sensor:

The coronagraphs inside SCExAO can be affected by low-order aberrations unseen by the PyWFS.

To correct them, SCExAO is equipped with a **Lyot-stop Low-Order Wavefront Sensor (LLOWFS)**, a type of focal plane WFS that uses the IR light rejected by the Lyot stop of the coronagraphs to measure and correct low-order aberrations. The camera used for the LLOWFS was also upgraded for a First Light Imaging C-RED 2 camera, that will improve performances especially for fainter targets.

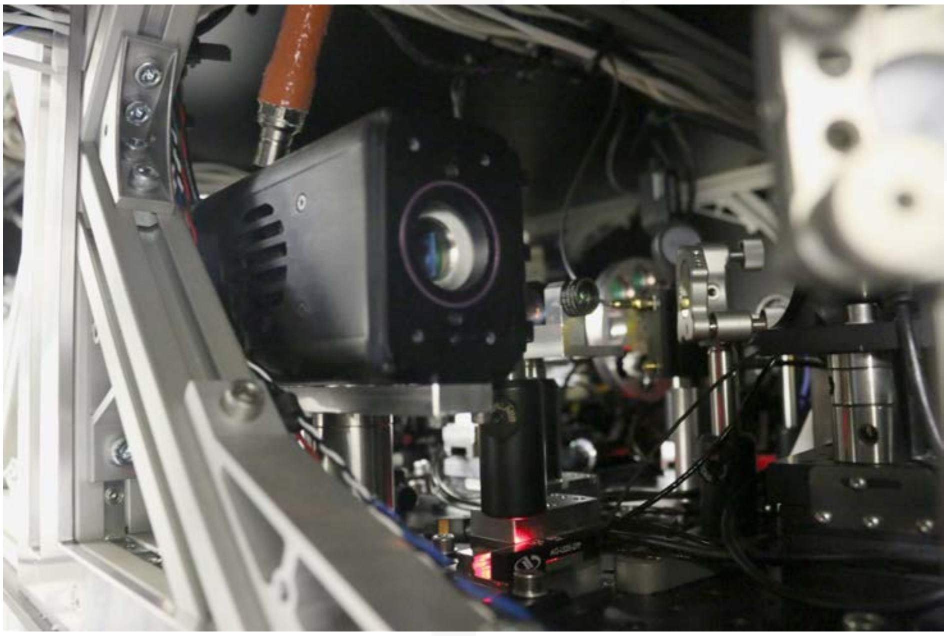

Fig. 2 : LLOWFS (Photo : J.Lozi, SCExAO)

Nulling Interferometry:

Interferometry is usually used to combine the light of 2 to several telescopes, to achieve a resolution equivalent to a telescope virtually the size of the baseline formed by the telescope.

This technique can also be used with only one telescope, by combining the light of different parts of the pupil. In this case, the resolution achieved with interferometry can by about half of the theoretical resolution of the telescope. Nulling interferometry uses this principle, but adds a phase shift between the different parts, creating a destructive interference.

SCExAO is equipped with the **Guided Light Interferometric Nulling Telescope (GLINT)** built by **the University of Sydney and Macquarie University,** a module that takes part of the IR light, select two beams in the pupil of the telescope, and make them interfere using integrated optics. The interferences are now dispersed on another First Light Imaging C-RED 2 camera, that detects chromatic variations in the destructive and constructive interferences. Using the statistics of these variations, it is possible to measure stellar diameters, as well as other resolved structures around bright stars.

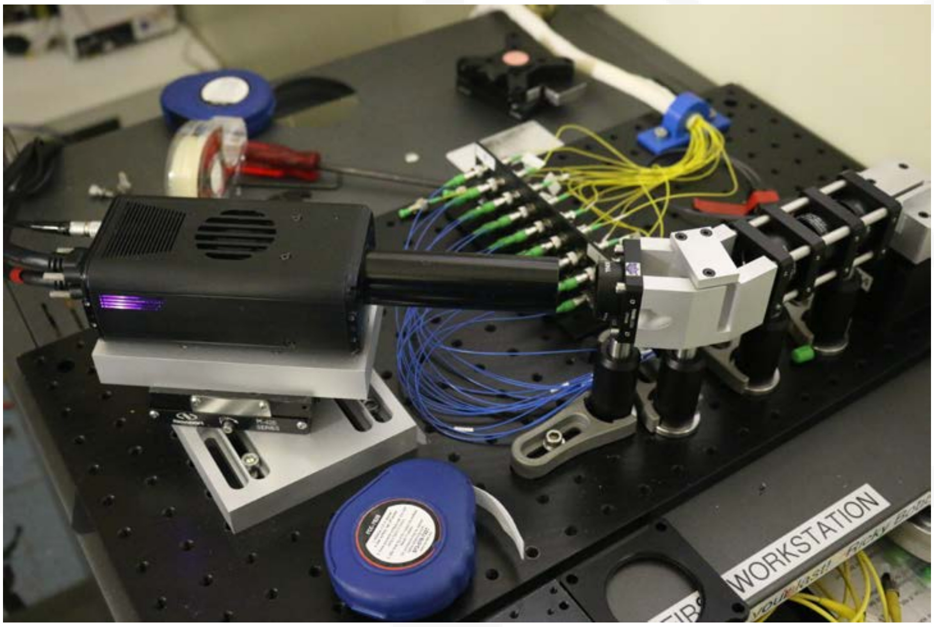

Fig. 3 : GLINT Spectrograph (Photo : J.Lozi, SCExAO)

C-RED ONE

More innovative focal plane wavefront sensing and advanced post-processing techniques developed in the context of the Horizon H2020 (ERC CoG #683029) KERNEL project hosted by **Observatoire de la Côte d'Azur** in France, will be tested starting June 2018 using a First Light Imaging C-RED One camera. It will use a similar path as SCExAO's internal C-RED 2 camera, but will be able to achieve much better precision.

With the C-RED One, we should be able to correct both quasi-static and variable speckles, resulting in deeper contrast in the final science image.

Update July 2018 (F.Martinache, KERNEL) : In its default full frame mode, the C-RED One makes it possible to acquire frames at 3.5 kHz. In its smallest window mode, the camera can run a little over 71 kHz. The high sensitivity of the camera, coupled with the high frame rate, are real game changers in the realm of high-contrast imaging and really make it possible to envision driving a deformable mirror directly from the focal plane. At these speeds, speckles don't stand a chance!

Fig. 4 : K-CAM: The KERNEL project C-RED-1 camera, is finally ready to observe on the IR side port of SCExAO. (Photo : F.Martinache, KERNEL)