The Subaru Coronagraphic Extreme AO Project: an XAO4ELT precursor

Frantz Martinache & Olivier Guyon

Project URL: http://www.naoj.org/Projects/SCEXAO/

Abstract:

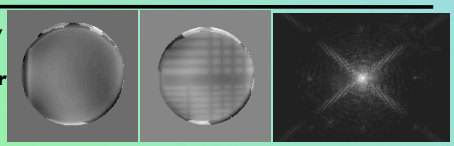
A diffraction-limited 30-meter telescope theoretically provides a 10 mas resolution limit in the near infrared. Modern coronagraphs offer the means to take full advantage of this angular resolution allowing to explore at high contrast, the innermost parts of nearby planetary systems to within a fraction of an astronomical unit: an unprecedented capability that will revolutionize our understanding of planet formation and evolution across the habitable zone. A precursor of such a system is the Subaru Coronagraphic Extreme AO project. SCExAO combines a high performance PIAA-based coronagraph downstream Subaru's AO188 AO system and a 1024-actuator MEMS DM. SCExAO employs advanced wavefront control schemes that make high contrast detection possible at 1 λ/D, providing for a few cases, the possibility to detect the light reflected by exoplanets. Moderate-high contrast detection in the super-resolution regime (<λ/D) is also possible using well calibrated closure quantities like closure-phase for a non-redundant (masked) aperture and its extension for to arbitrary apertures (Kernel-phase). Lessons learned from SCExAO's incremental deployment plan during its first 2011 engineering campaign provides insights that will guide future development of high contrast instrumentation on an ELT.

A series of adapted wavefront control strategies

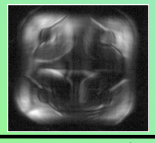
1. Use Subaru Facility AO188 for starters...

2. Coronagraphic LOWFS for ultra-fine (sub-mas) pointing control (IR)

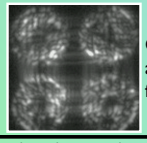
3. Phase-diversity based OPD and DM calibration for static speckles (IR)



4. Visible High-order Pyramid wavefront sensor for dynamic aberrations



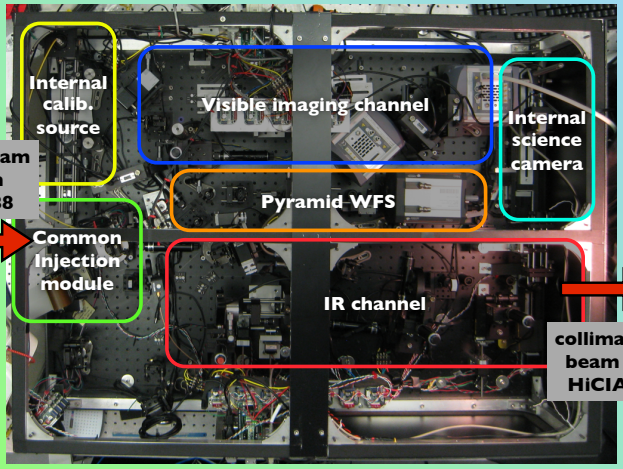
Ref. image acquired on internal calibration source



On-sky data at ~1 kHz frame rate

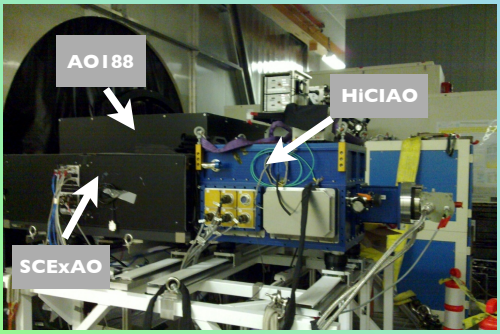
5. Speckle nulling to create a high-contrast region in the image

Under the hood



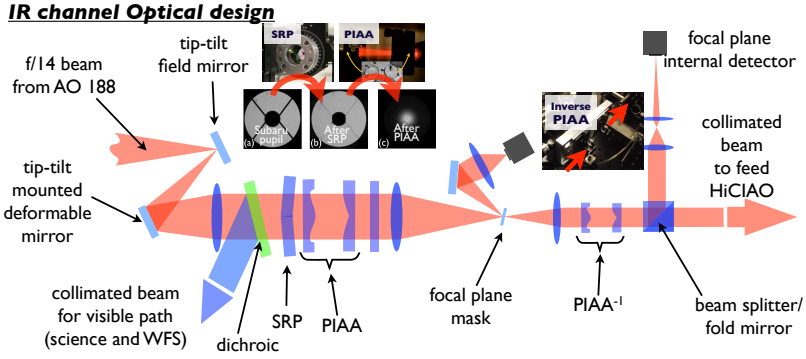
SCExAO engineering observations

SCExAO is an upgrade to the existing coronagraphic imager HiCIAO, used with Subaru's in house AO system..



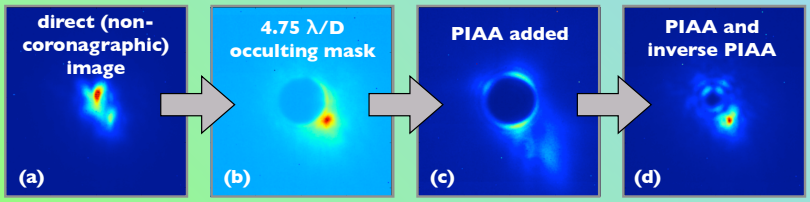
SCExAO on the Subaru IR Nasmyth platform, before craning behind AO. On September 11, 2011, SCExAO had its first engineering observing night with acceptable observing conditions.

IR channel Optical design



First on-sky demonstration of small IWA coronagraphy by PIAA

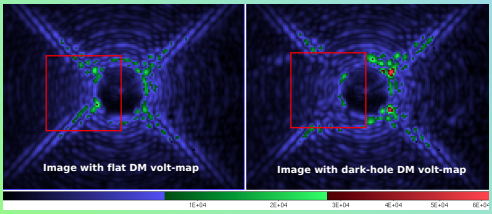
Images acquired on the binary star HIP101769 (separation: 0.238" i.e. ~6 λ/D in H-band) in four different optical configurations of SCExAO. Compare the apparent change of size of the focal plane mask in panels **b** (4.75 λ/D Lyot-type coronagraph), and **d** (1.5 λ/D PIAA-coronagraph):



The inclusion of PIAA and PIAA^{-1} successfully boosts the IWA by a factor of 3!

Speckle control

Use DM commands (e.g. sine waves) to iteratively probe the coherence of speckles in the field and actively cancel out the static aberrations, within the 0.5" f.o.v. of the instrument.



Example of speckle nulling result after 30 iterations: the average speckle level in the control box is reduced by a factor > 10.

SCExAO on an ELT could detect an exo-Earth in reflected light!

Because it works on a very small f.o.v, optical interface requirements are minimum: SCExAO could directly be mounted on an ELT with minimal adjustments.
The angular resolution boost will open up exclusive science cases: probe habitable zone of 'nearby' systems, and detect planets in reflected light (c.f. Guyon talk, this conference)

References:

Martinache et al, 2011, SPIE, 8151, 36
Lozi et al, 2009, PASP, 121, 1232
Guyon et al, 2010, PASP, 122, 71
Guyon et al, 2009, ApJ, 693, 75
Vogt et al, 2011, PASP, submitted