New calibration source for AO3k

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I. AO3k: NEED FOR A NEW POLYCHROMATIC SOURCE

AO188's calibration source AOCAL uses three laser diodes. One at 633 nm (red), one at 1550 nm (IR), one a 589 nm (sodium wavelength). It does not include a pupil mask, but has two wheels simulating atmospheric turbulence.

The upgrade of AO188 to AO3k includes:

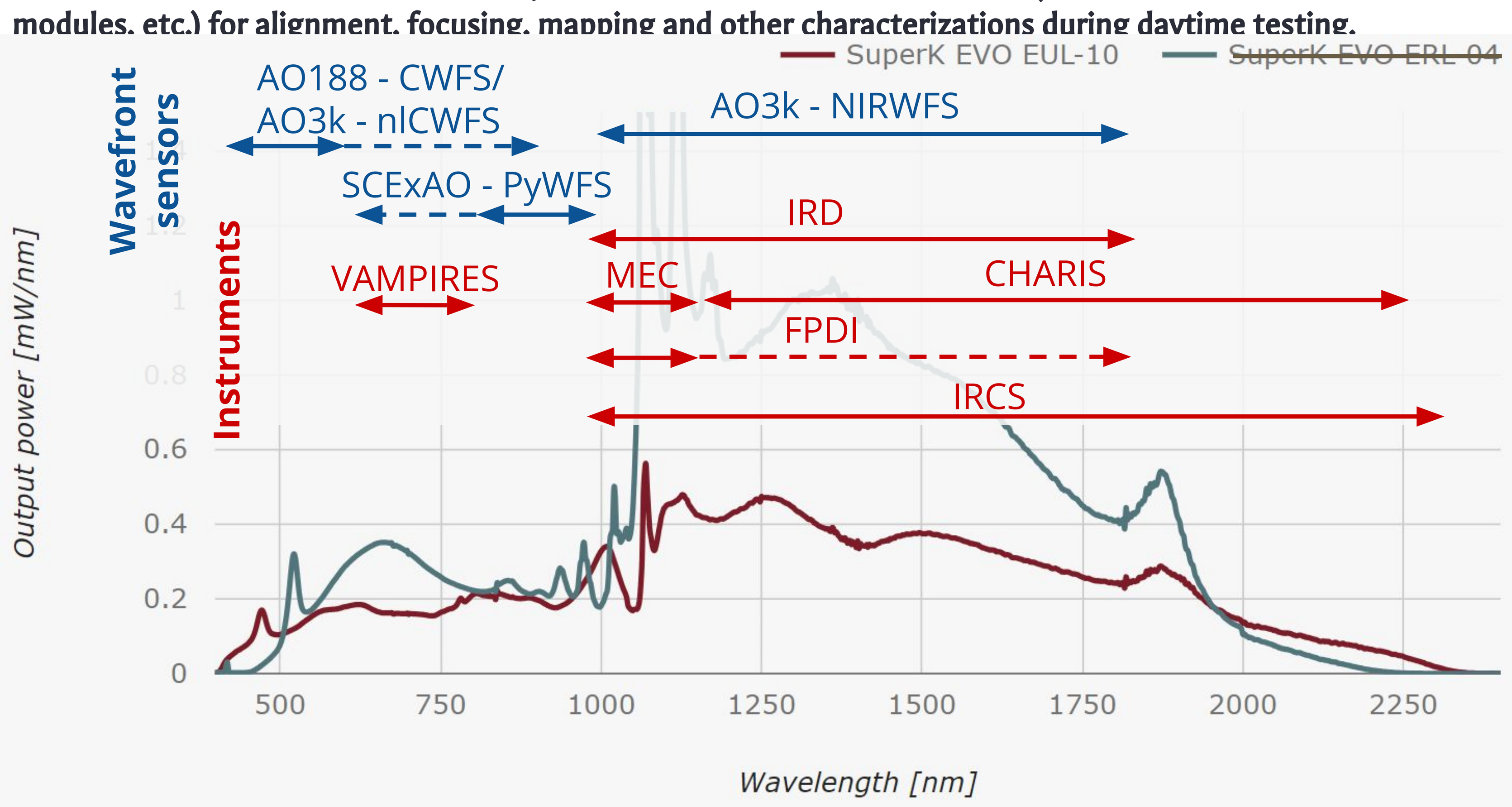
- new 3000-actuator deformable mirror (DM3k)
- new Near Infrared Wavefront Sensor (NIRWFS)
- new non-linear Curvature Wavefront Sensor (nlCWFS).

AO3k's performance is vastly superior to AO188, but it requires a precise calibration of its wavefront sensors.

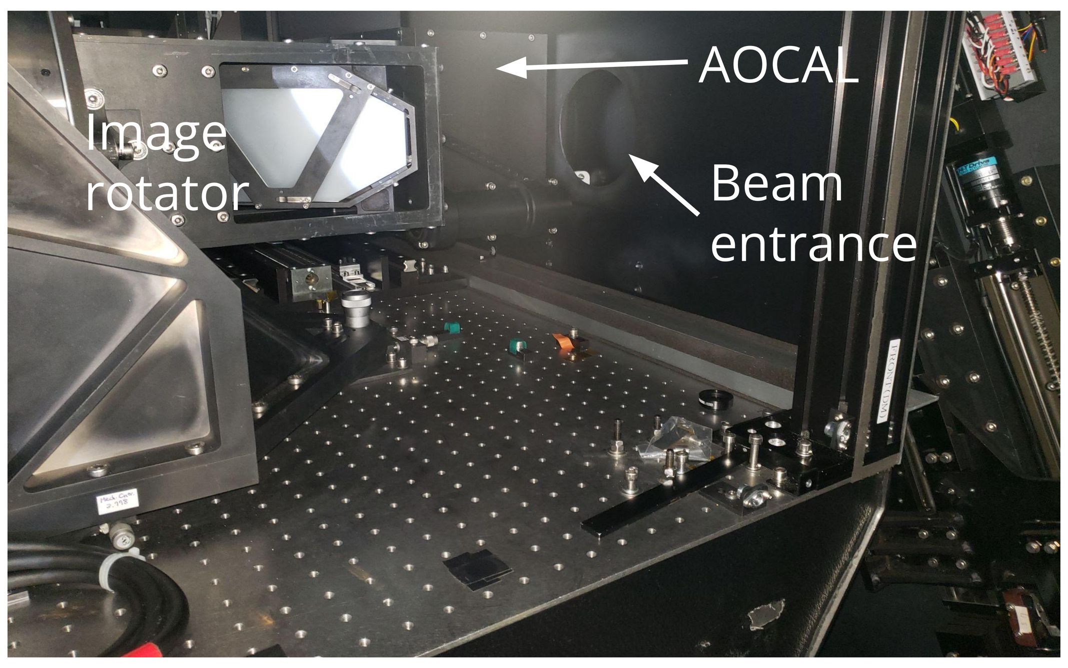
A new source with the following characteristics is needed:

- Polychromatic instead of laser diodes, with the use of a supercontinuum laser (same as SCExAO's source). This will allow to test the polychromatic mode of the nlCWFS (dichroic beamsplitter used), and include chromatic effects in the calibration of the NIRWFS.
- A pupil mask simulating Subaru's pupil. The lack of pupil mask in the current source is creating a sub-optimal response for the calibration of the wavefront sensors. The pupil mask can be fixed, and rotation can be performed with the image rotator.

The same source can also be used by science instruments downstream (IRD, IRCS, SCExAO and its modules, etc.) for alignment, focusing, mapping and other characterizations during daytime testing.



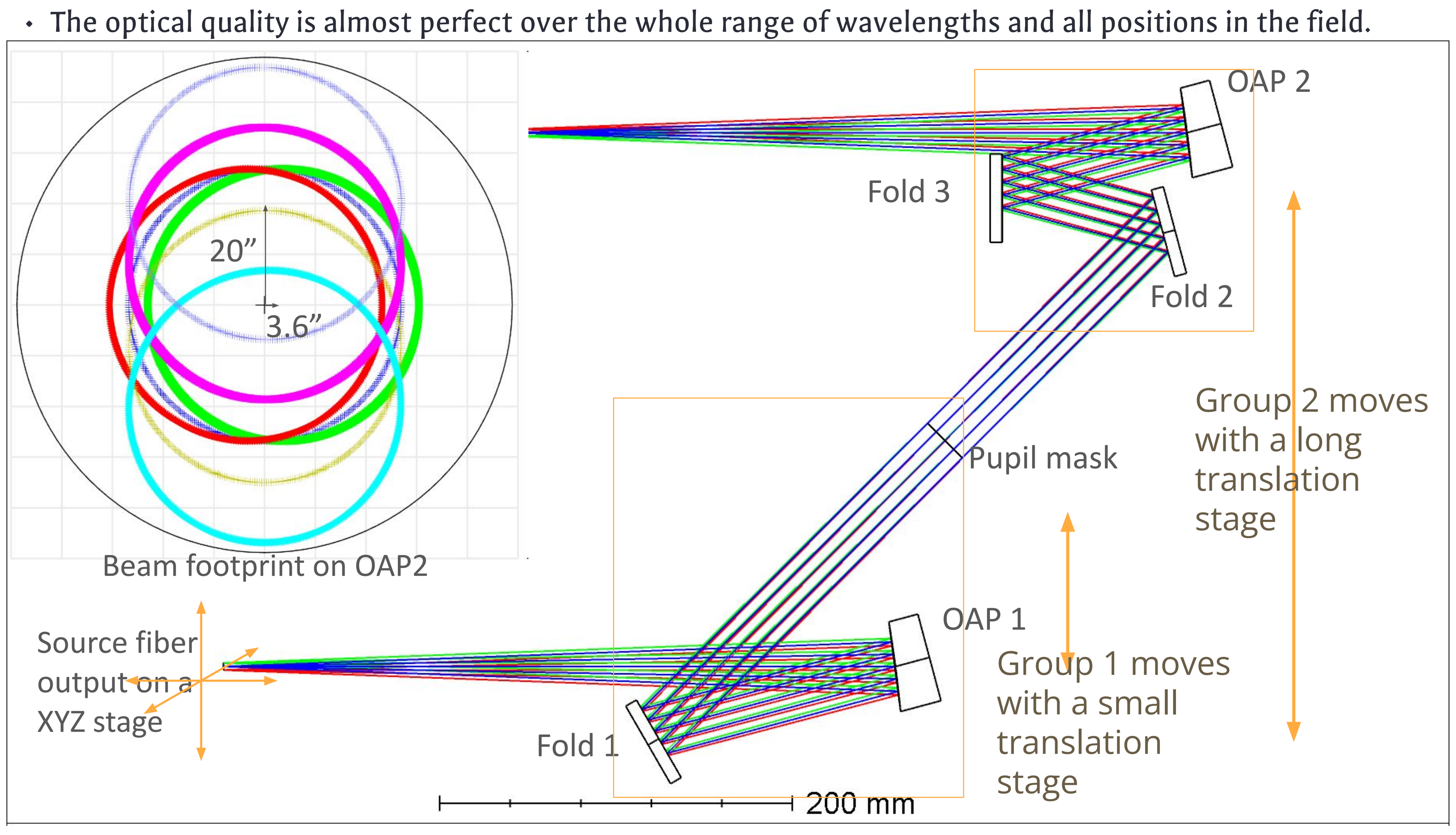
Top: Spectrum of the supercontinuum source shared between AO3k and SCExAO (red) overlaid with the various wavefront sensors and instruments that can benefit from it.
Right: Location of the new source, next to AOCAL and in front of the image rotator. We decided to add the source instead of upgrading AOCAL to keep the current functionalities, and as an easier upgrade due to the physical size and location of AOCAL.



II. OPTICAL DESIGN

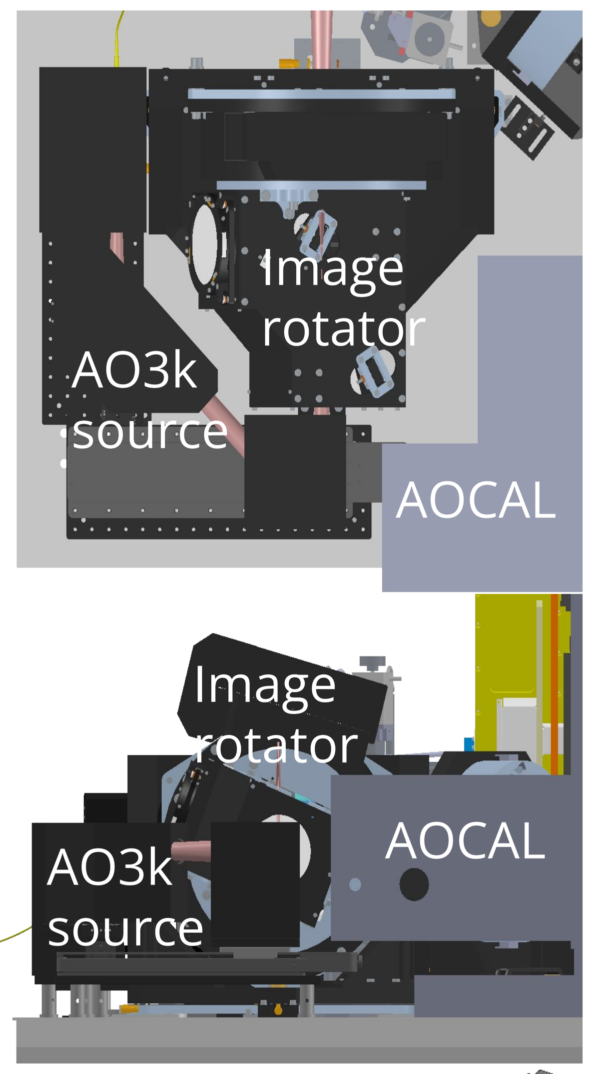
Due to the large wavelength coverage of the polychromatic source, the optical design is based on off-axis parabolas (OAP) and flat mirrors.

- Since the focal plane is inside the image rotator, The OAP's focal length has to be large enough to clear the IMR, but short enough to have a reasonable beam size for the f/13.9 beam. The only off-the shelf solution is the Thorlabs MPD2151-P01. It has a 2" diameter, a 381 mm focal length, and 15 degrees of off-axis angle. With this focal length, the beam diameter would be 27.4 mm.
- The source is collimated by OAP 1, then through a series of fold mirrors, the collimated beam goes through a pupil mask at a distance f_{OAP}, and the focusing OAP 2 at a distance $2f_{OAP}$.
- 3 fold mirrors are necessary to fit in the available space. Fold 3 is designed to be as close as possible to the IMR, and due to the shallow angle of the OAPs, the beam reflects close to the edge of the mirror.
- The OAPs are oriented in such a way so that they compensate for each others astigmatism.
- Moving the fiber in X and Y allows a range of ±20" vertically and ±3.6" horizontally, due to the position of Fold 3. But by moving all the components horizontally instead, we can get a range of ±22.5" horizontally.
- The optical quality is almost perfect over the whole range of wavelengths and all positions in the field.



Zemax optical design. The optics are grouped in two groups that will not collide when the source is retracted. Each group is motorized on one axis separately, and the fiber itself is on a separate XYZ stage.

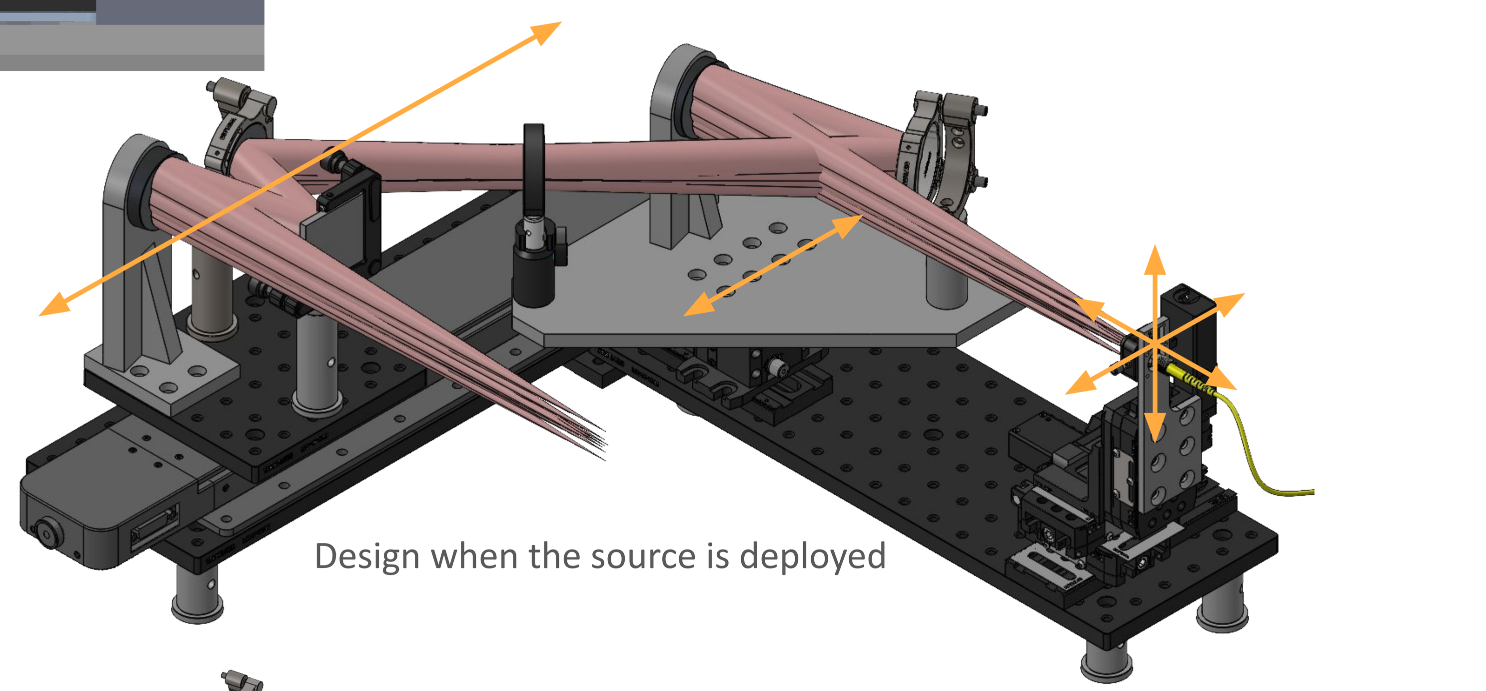
III. MECHANICAL DESIGN

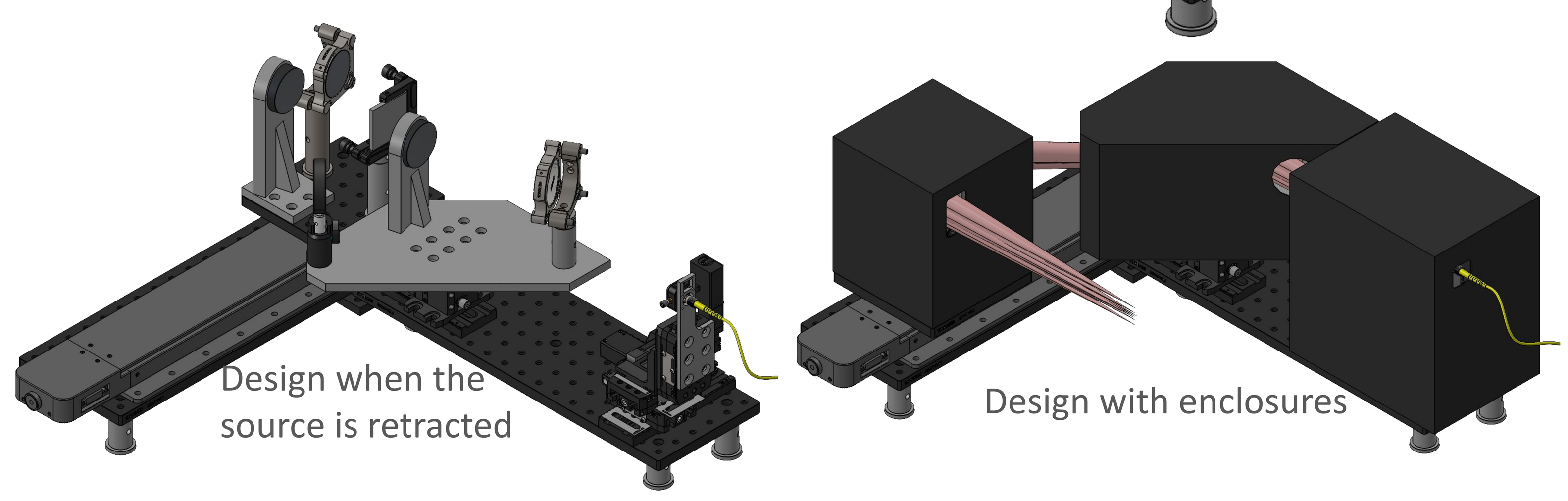


The mechanical design has to fit inside a L-shaped footprint next to the image rotator, and take into account the motion of AOCAL when it is used or retracted.

- It is using off-the-shelf parts as much as possible. Two 150x450 mm raised plates arranged in a L shape constitute the base. A 300 mm OptoSigma translation stage is used for group 2, while a Thorlabs 25 mm translation with a Zaber motor moves group 1. The source uses a Thorlabs 3-axis 25 mm stage, also powered by 3 Zaber motors.
- The three optics of group 2 are attached to a 150x150mm plate, while the three optics of group 1 are attached to a custom plate. OAPs are mounted in fixed custom mounts, while the others are mounted in off-the-shelf adjustable holders.
- When the original source is retracted, the new source can be inserted by moving group 2 in front of the image rotator.
- Interlocks are necessary for the operation of both sources: one can only be used if the other one is retracted completely .
- The design includes baffles to avoid any stray light when in use.
- Clearances were checked to avoid any collisions with the IMR and AOCAL when they are in motion.

Top: CAD model of AO3k when the source is inserted and AOCAL is retracted.
Right: CAD model of the source with optical beams, with and without baffles, deployed and retracted.

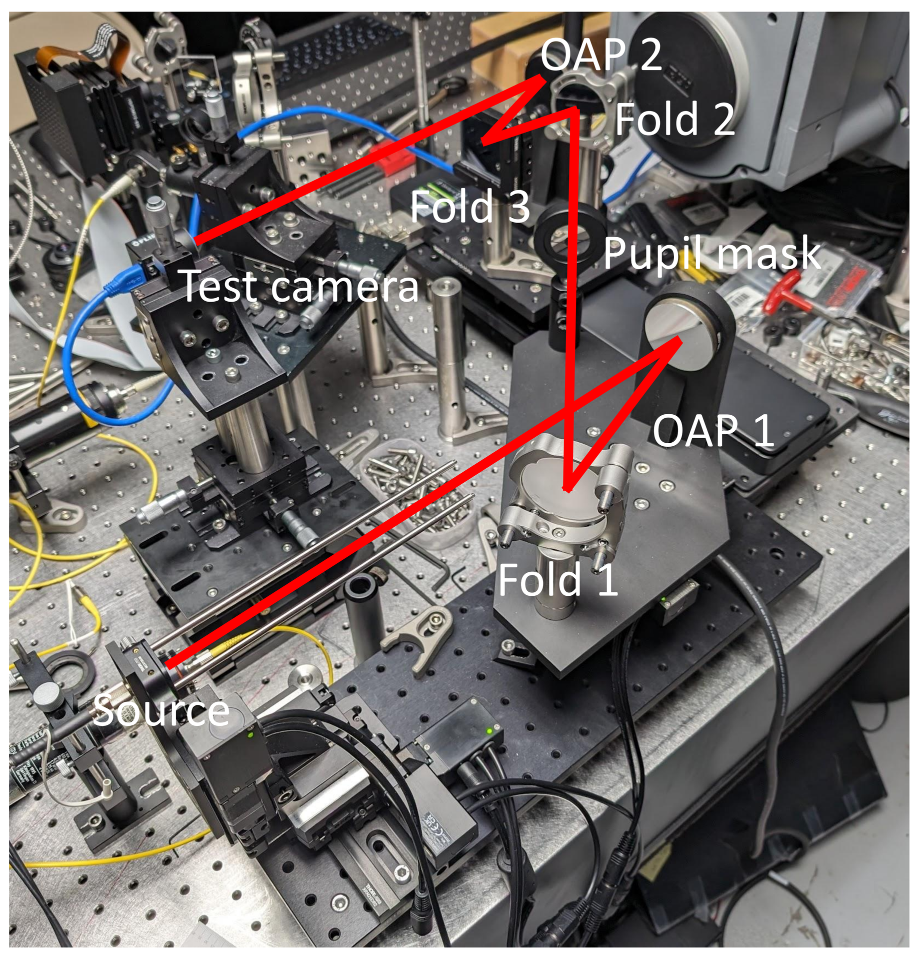




IV. TEST AND INSTALLATION SCHEDULE

The source was assembled and tested in the sim lab in Hilo. A red laser (633 nm) was used for the alignment, and the source was tested with the supercontinuum source as well.

- A small test camera in the output focal plane was used for the alignment. It was placed on a X/Y/Z stage, with limited range of motion.
- The alignment of OAPs is not trivial, especially when the OAPs are fixed and the degrees of freedom are on the fold mirrors. But an alignment procedure was devised.
- The image quality after alignment is looking great, with only small low-order errors visible.
- The high-frequency noise in the pupil images is probably coming from the polishing of the OAPs, but it should not impact the quality of calibrations too much.
- A 2 µm pinhole is placed in front of the fiber tip to get a better uniformity of the illumination in the pupil, when the supercontinuum is used, especially for short wavelengths (400 - 600 nm).
- We tested the motion of the source (limited range in the test setup), and confirmed the optical quality does not degrade.



We hope to install the source in February 2025, to characterize the wavefront sensors before the engineering nights in March 2025.

Top: Test setup after assembly, in the Sim lab in Hilo. A red laser and a small test camera was used for the alignment.
Right: Pupil images with the red laser and the supercontinuum source, with and without the pinhole. The pinhole provides a more uniform illumination. The Subaru pupil mask is visible here, with the spiders and central obscuration.
Bottom: Focal plane images with the red laser, after alignment. Moving the source does not degrade the image quality, as expected.