

Characterization and on-sky testing of high-resolution photonic, AWG-based astronomical spectrographs

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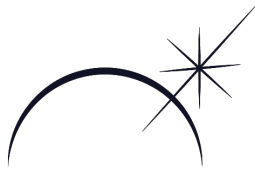
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**OBSERVATOIRE
DE LA CÔTE D'AZUR**



UNIVERSITÉ CÔTE D'AZUR



Outline



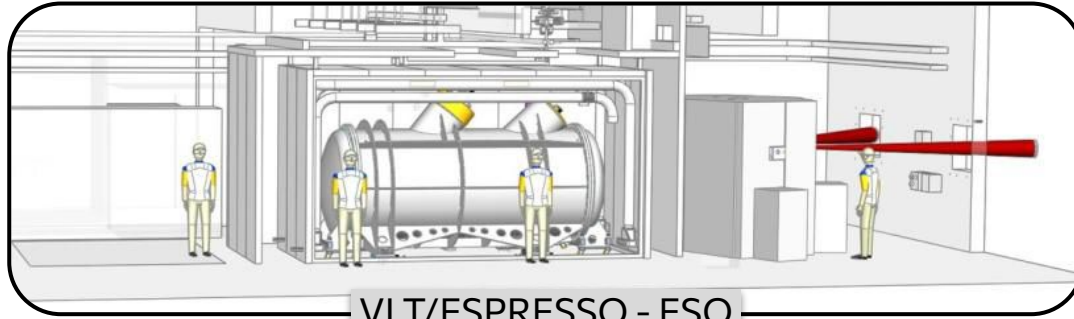
1. Bulk optics vs photonics for spectroscopy
2. AWG spectrographs.
3. The *CoLiBRIS*-AWG spectrograph prototype at OCA/Lagrange.
 - a. In-lab Characterisation
 - b. On-sky testing at OHP
4. Preliminary results



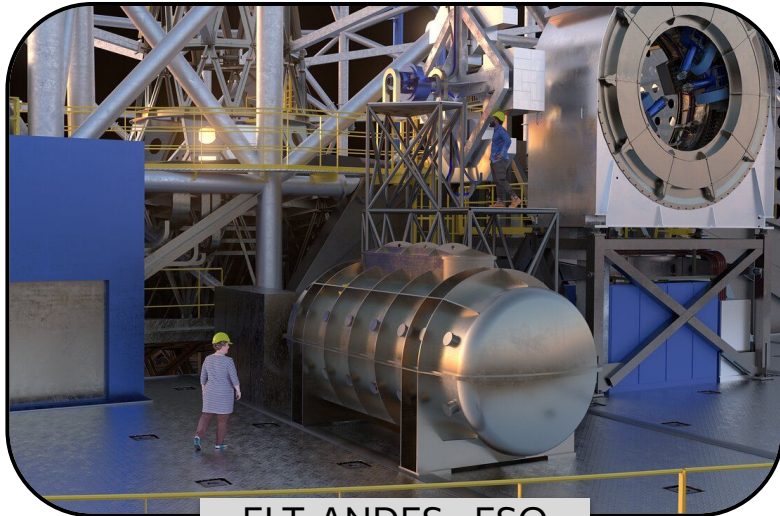
Macaulay Library - F. Oñate

1. Bulk optics vs photonics

Spectrographs are bulky



VLT/ESPRESSO - ESO



ELT-ANDES - ESO



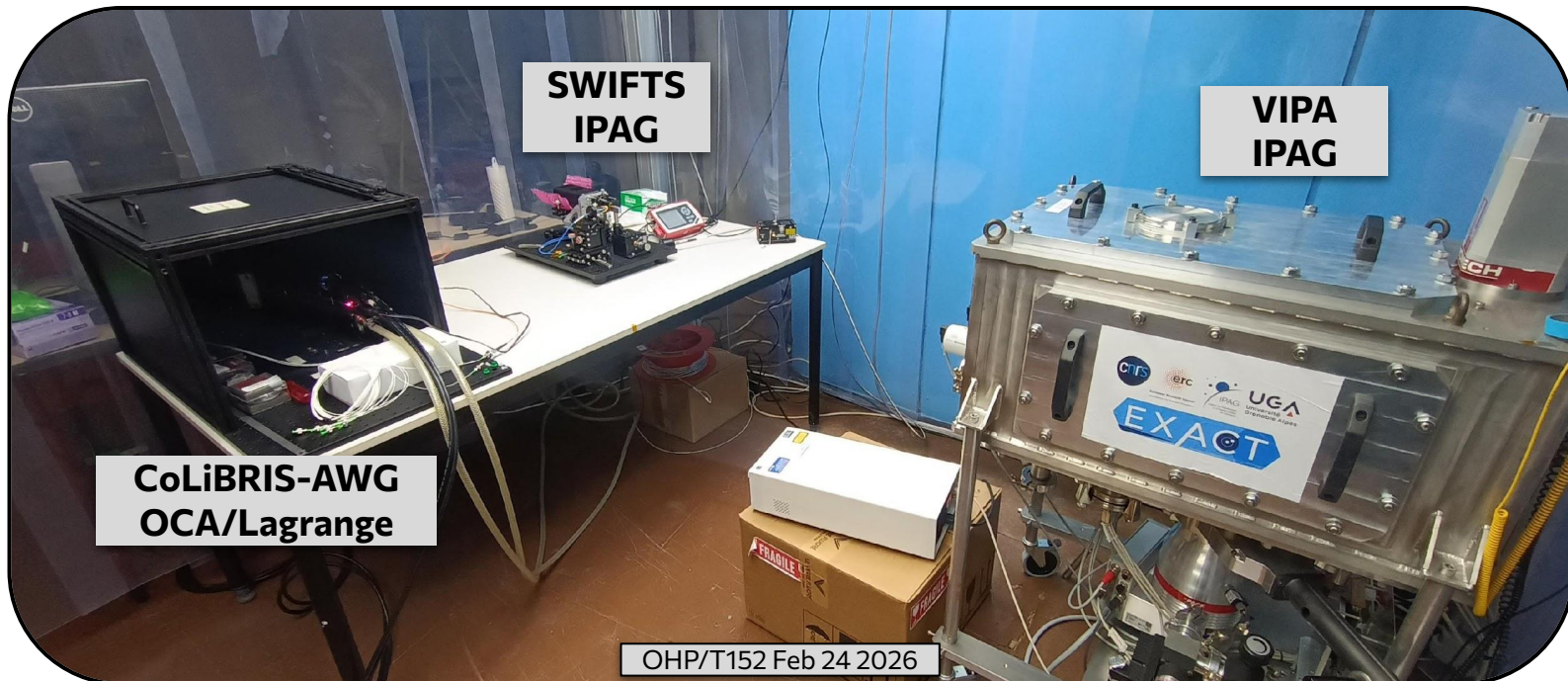
JWST/NIRSpec - ESA+NASA



But do they have to be?

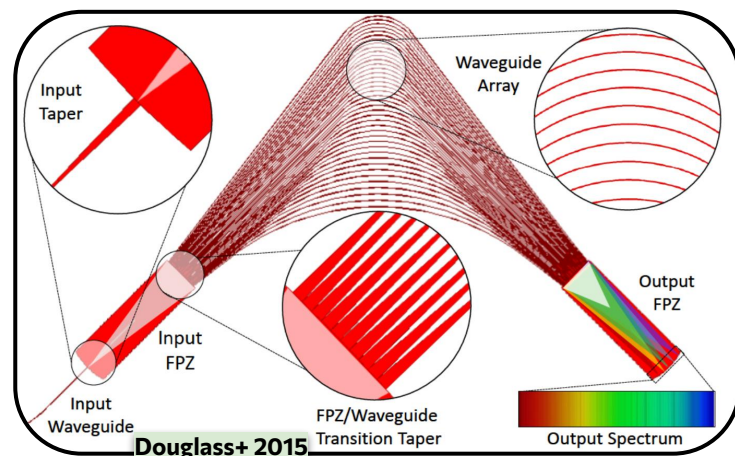
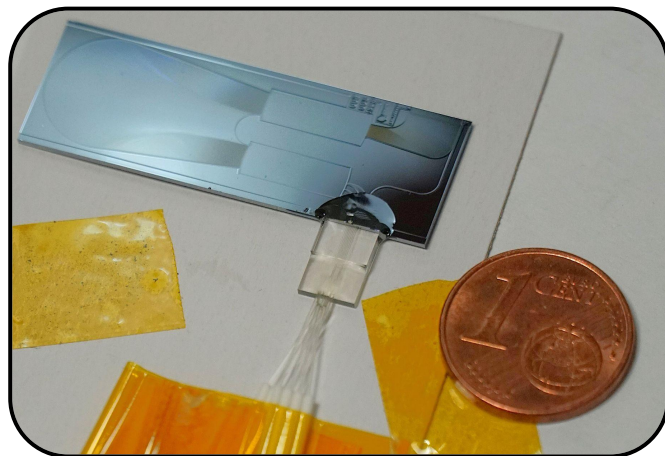
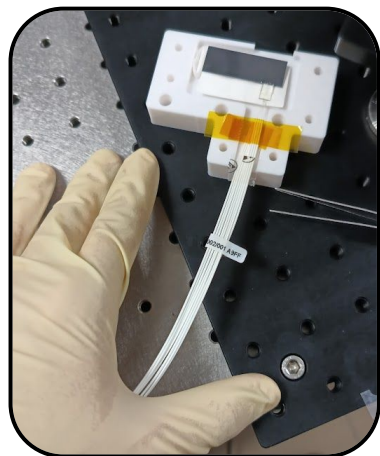
The astrophotonics approach allows for more **compact, stable, modular and reproducible** instruments!

Compact (photronics-based) Spectrographs!

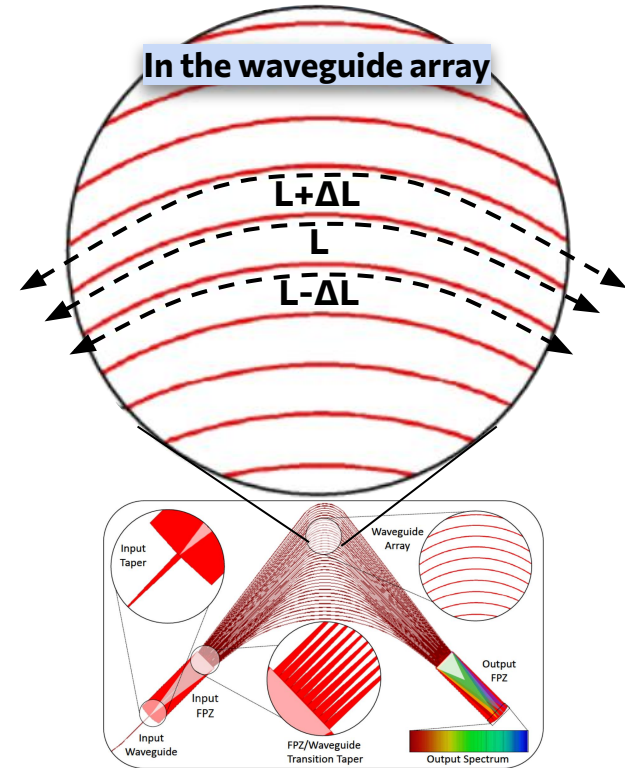
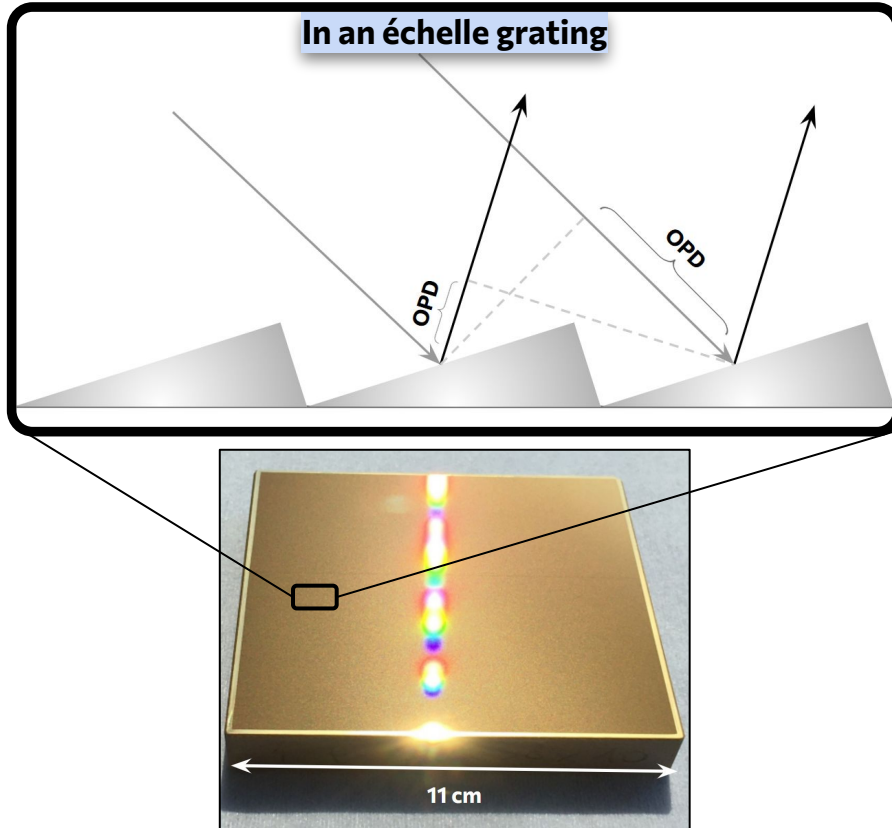




2. Arrayed Waveguide Gratings (AWGs)

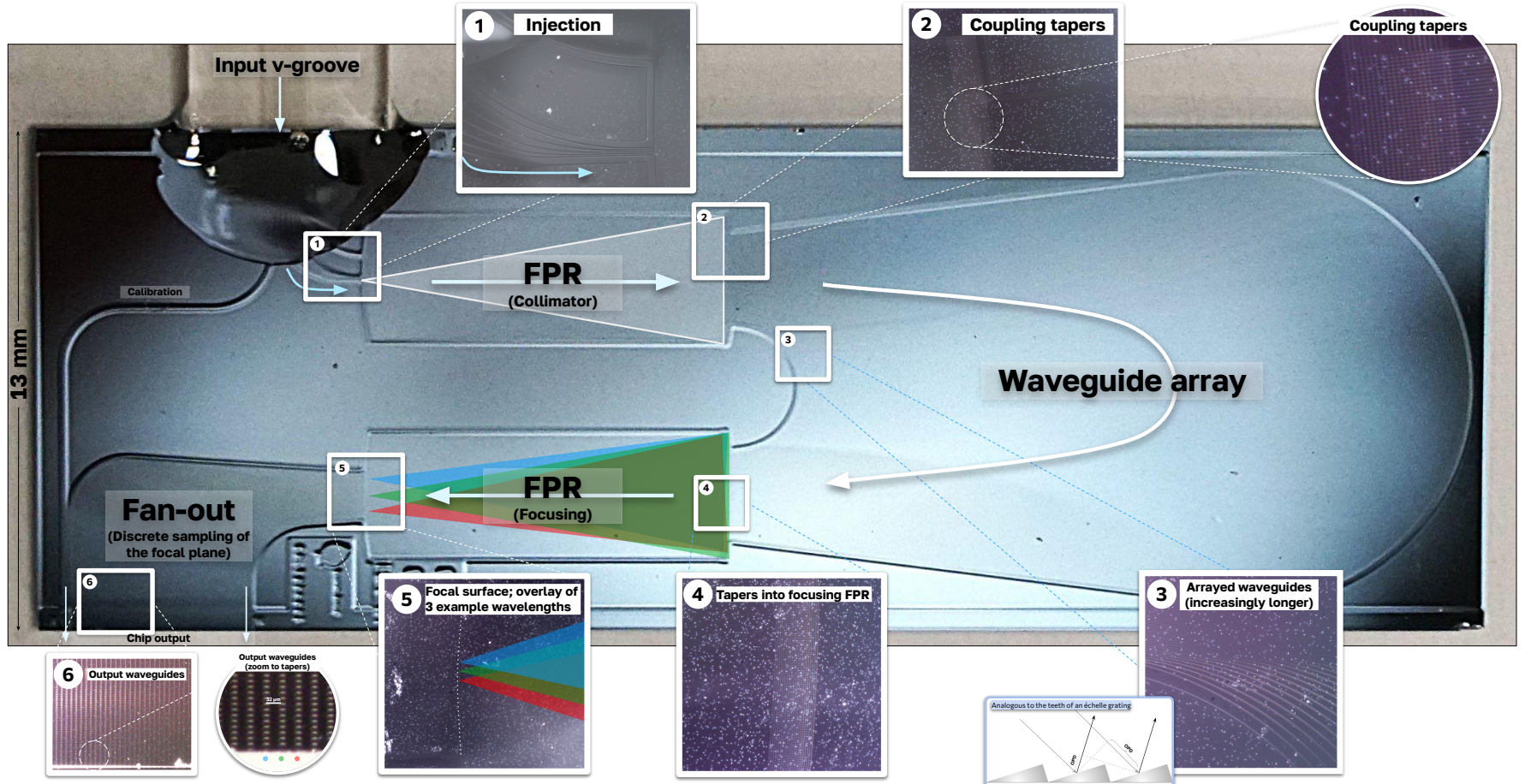


AWGs vs échelle gratings



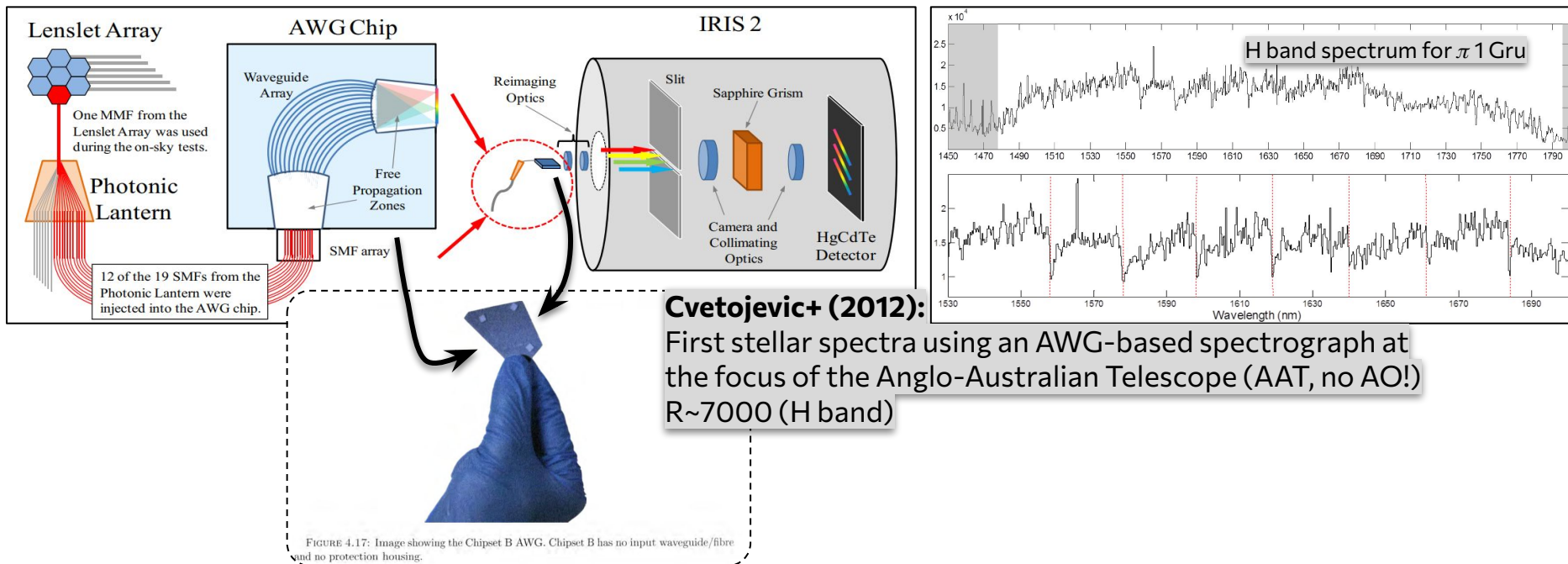
ΔL is chosen to optimize the dispersion around a reference wavelength

Light's journey inside the AWG chip



AWG-based spectrographs for astronomy

AWGs as main dispersers of **astronomical spectrographs!**
 Replacing bulky prisms/gratings with a chip of a few cm² of surface.





3. The **CoLiBRIS**-AWG spectrograph prototype at OCA/Lagrange.

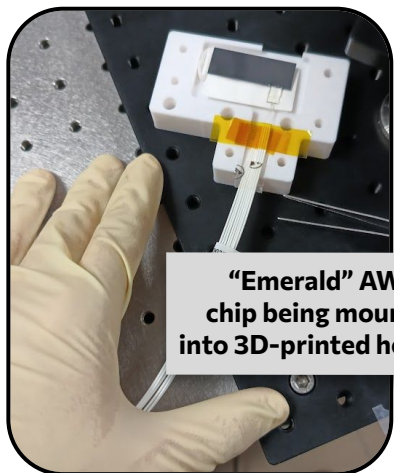
Our prototype: CoLiBRIS-AWG

Compact **L**ightweight **B**roadband high-**R**esolution **I**nfrared **S**pectrographs - AWG

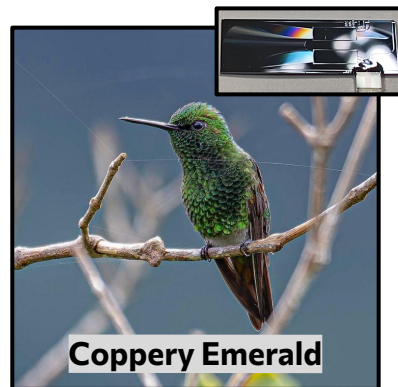
The setup is used to test different AWG chips. Currently two chips are in use:

- **Emerald (R~18000, H band)**, smaller chip.
- **Sapphire (R~36000, H band)**, larger chip.

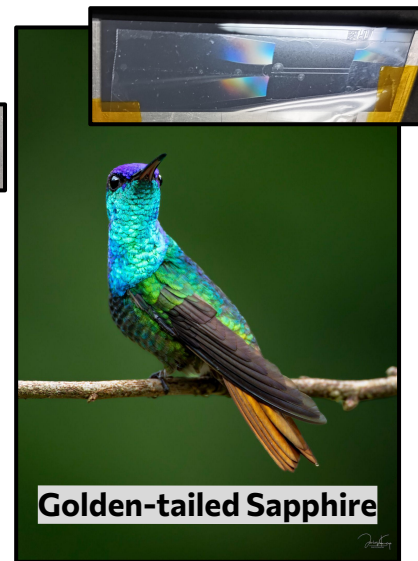
The idea is to design new chips with more sophisticated applications of the AWGs.



"Emerald" AWG chip being mounted into 3D-printed housing

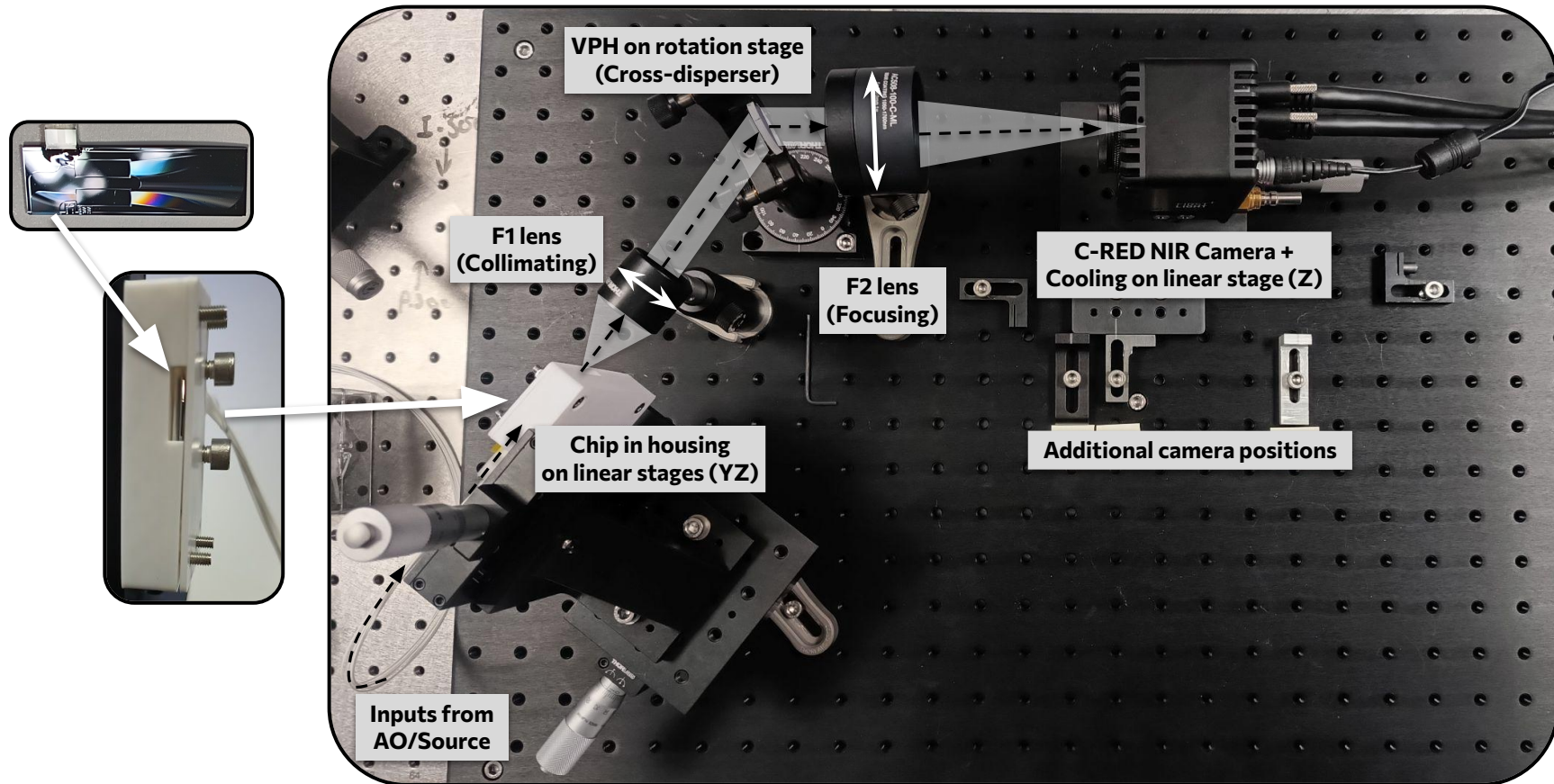


Coppery Emerald

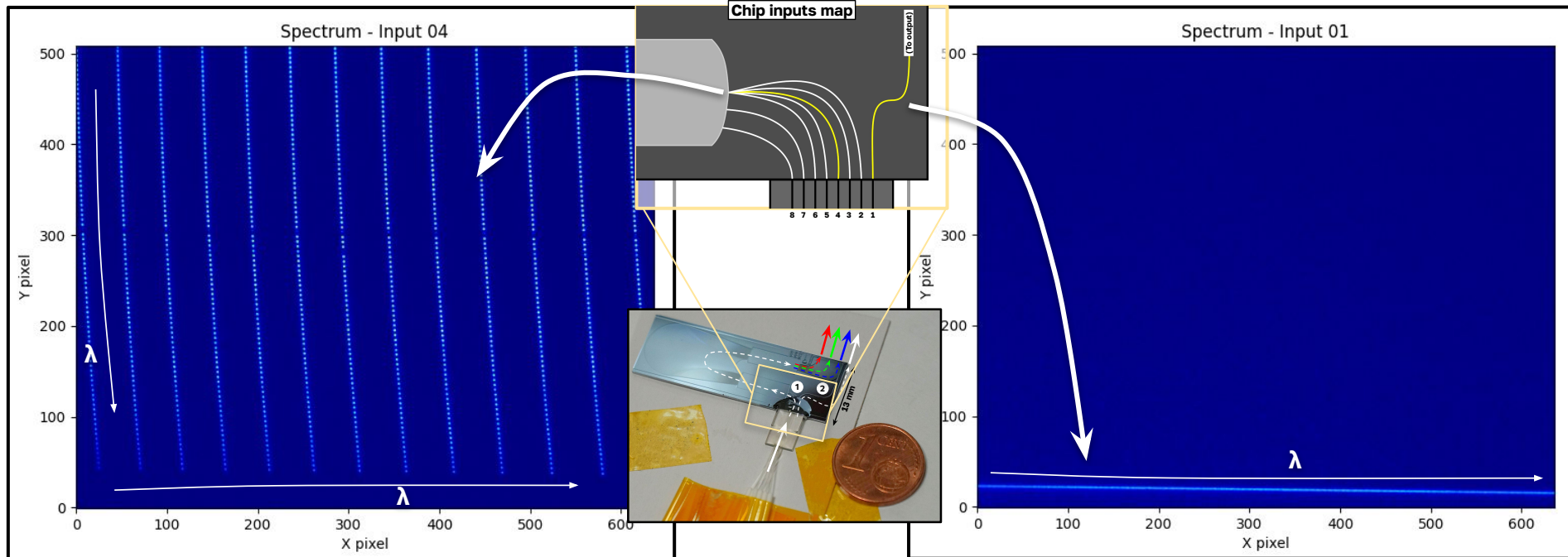


Golden-tailed Sapphire

Our prototype: CoLiBRIS-AWG



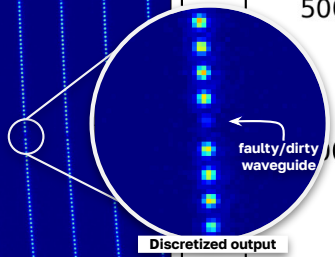
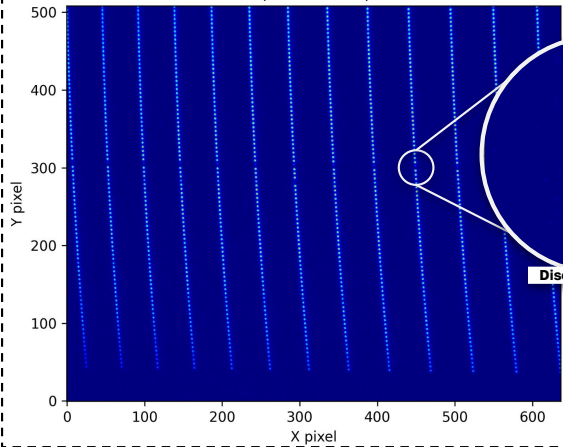
The datasets: AWG vs Straight-through channel



Setups for waveguide diagnostics, and measuring **spectral resolution ($R \sim 18000$)**, **throughput (TBD)** and spectral **coverage (1440–1630 nm)**.
Prototype used for on-sky tests at OHP/T152+PAPYRUS!

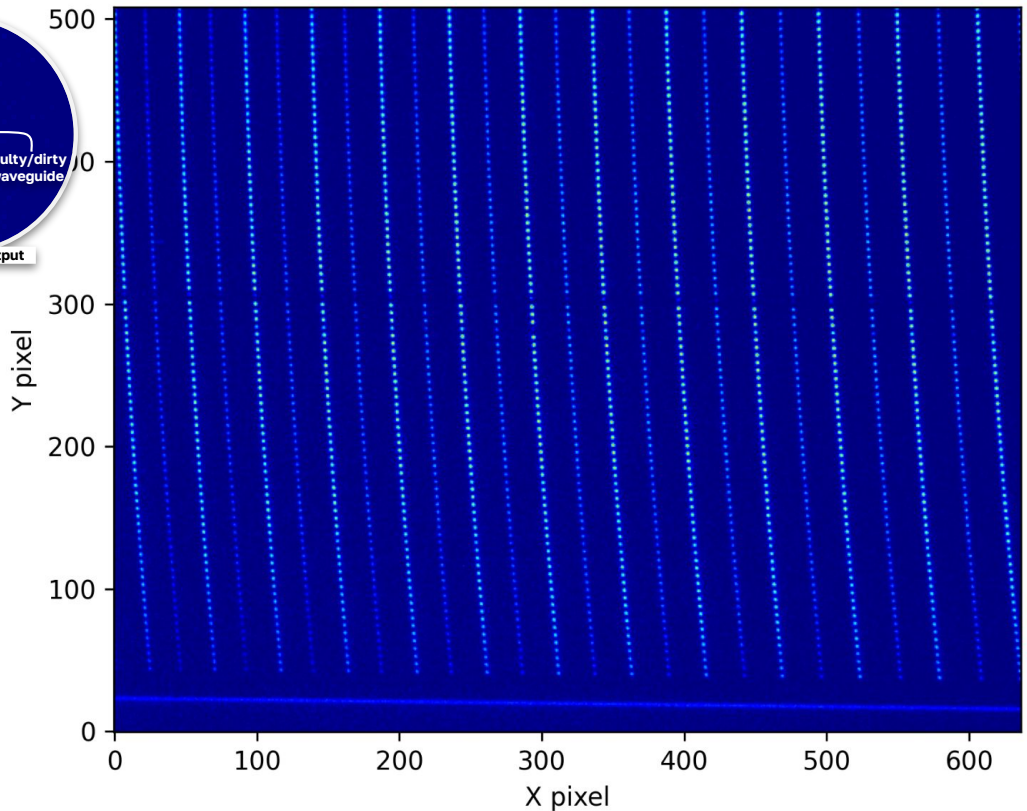
Multiple input tests

AWG spectrum, single input fed with broadband source, cross dispersed by VPH grating

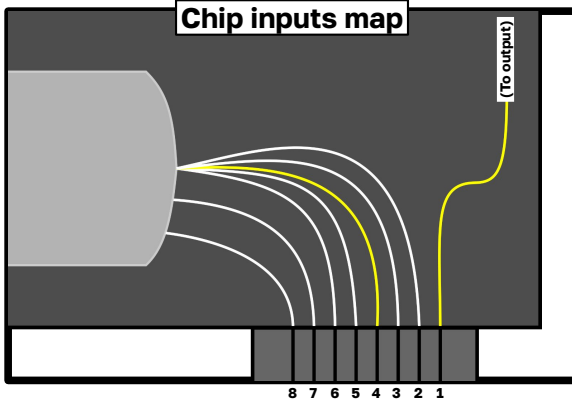


AWG spectra, multiple inputs fed with broadband source, cross dispersed by VPH grating

Stacked AWG spectra - Inputs 1, 4 and 7



Chip inputs map

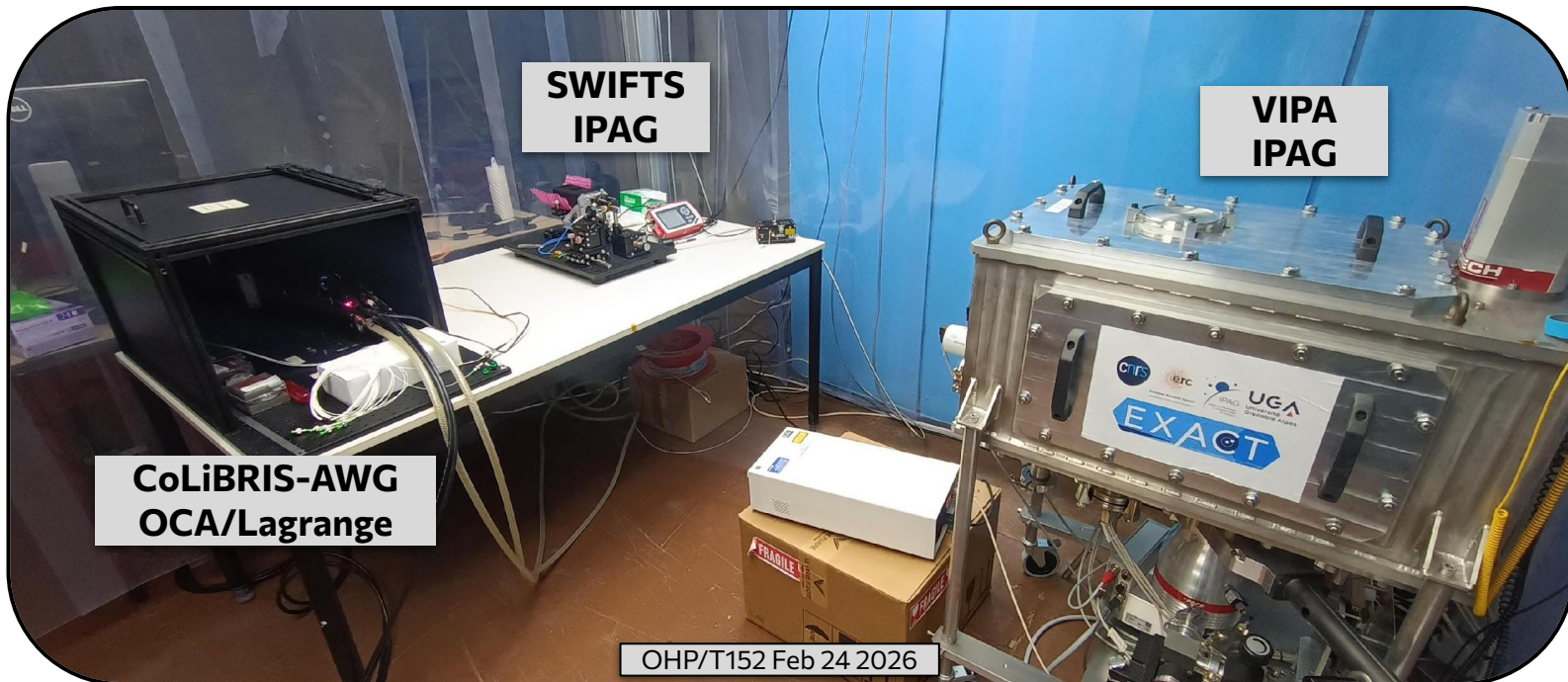




On-sky testing!

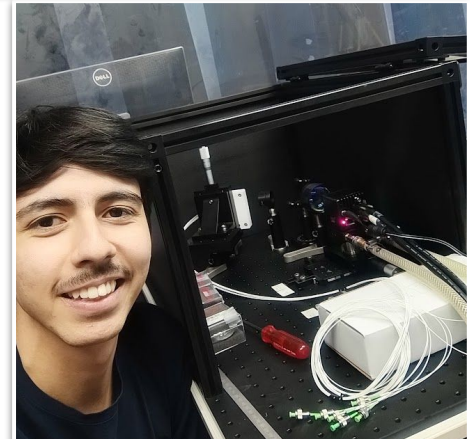
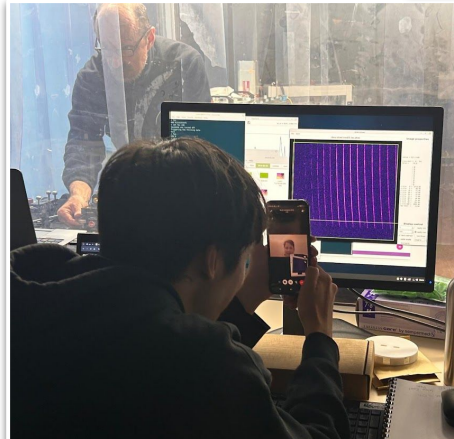
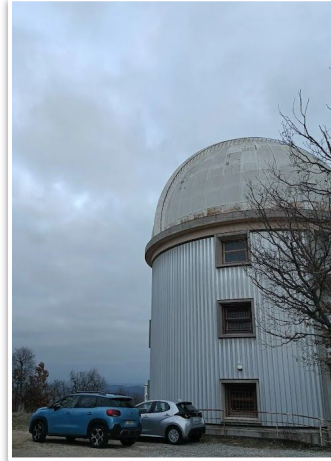
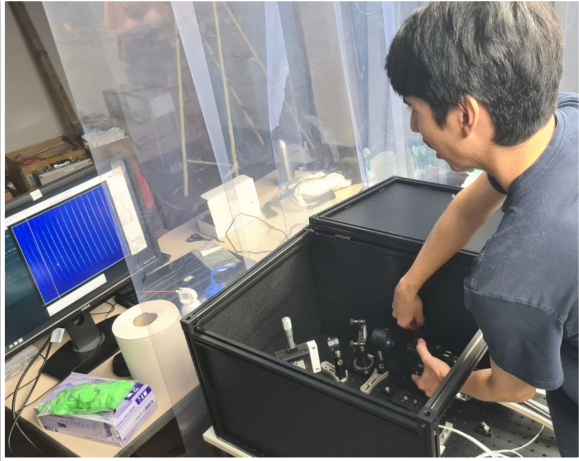
Observing run in **Feb 2026**

PEPR Origins - Compact Spectrographs Collaboration



With **LAM** providing a common on-sky testing platform (e.g. the **PAPYRUS AO system**)

First Light observing run: OHP 24-26 Feb, 2026



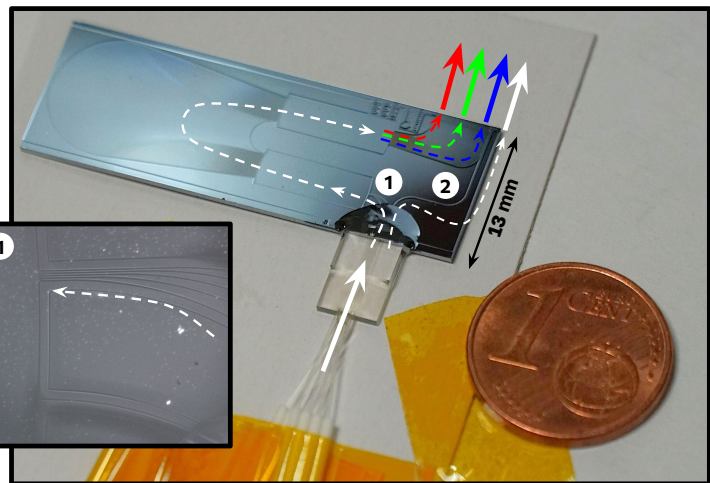
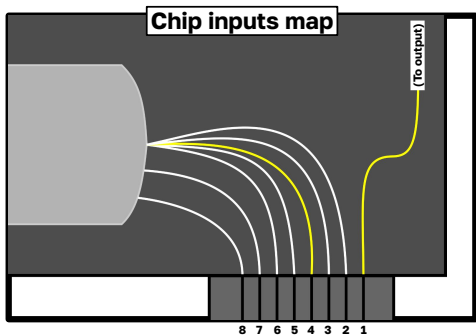


Macaulay Library - Anonymous

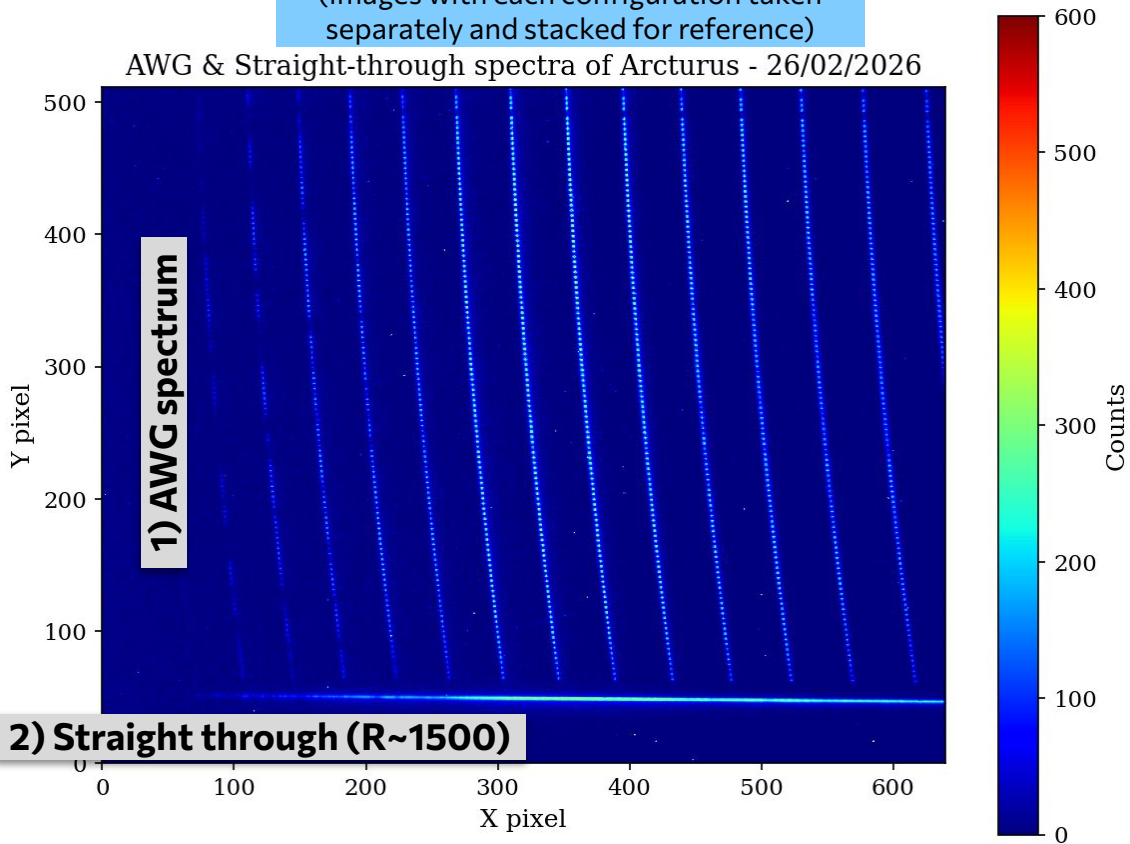
4. Preliminary results

First light

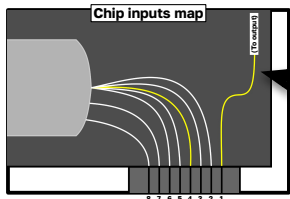
(images with each configuration taken separately and stacked for reference)



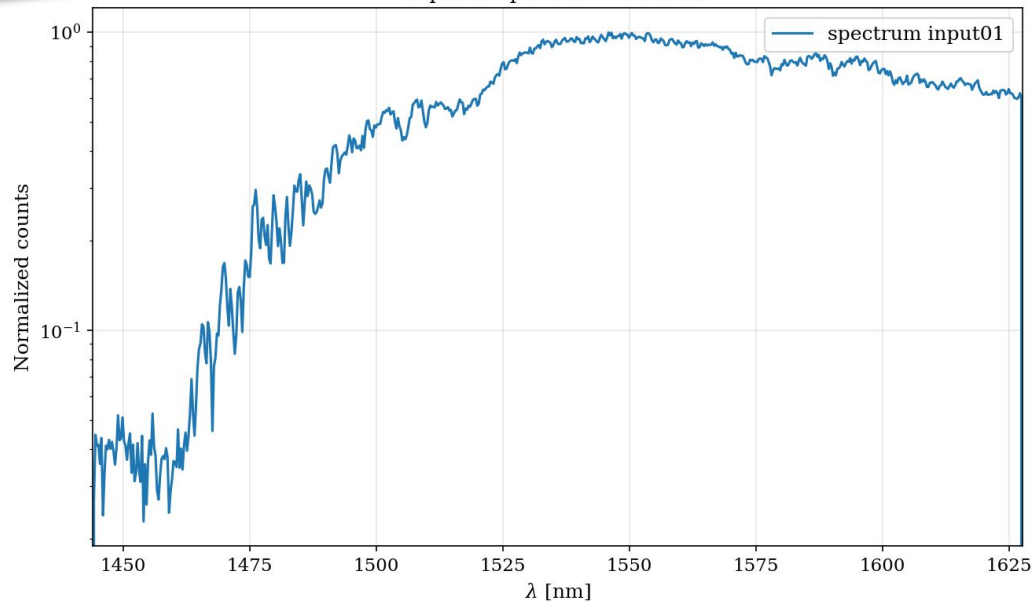
AWG & Straight-through spectra of Arcturus - 26/02/2026



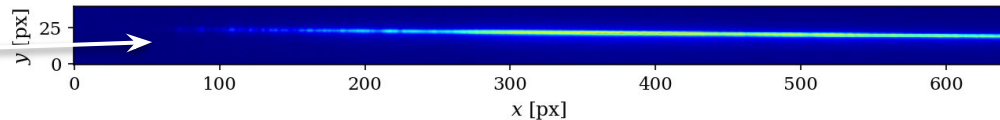
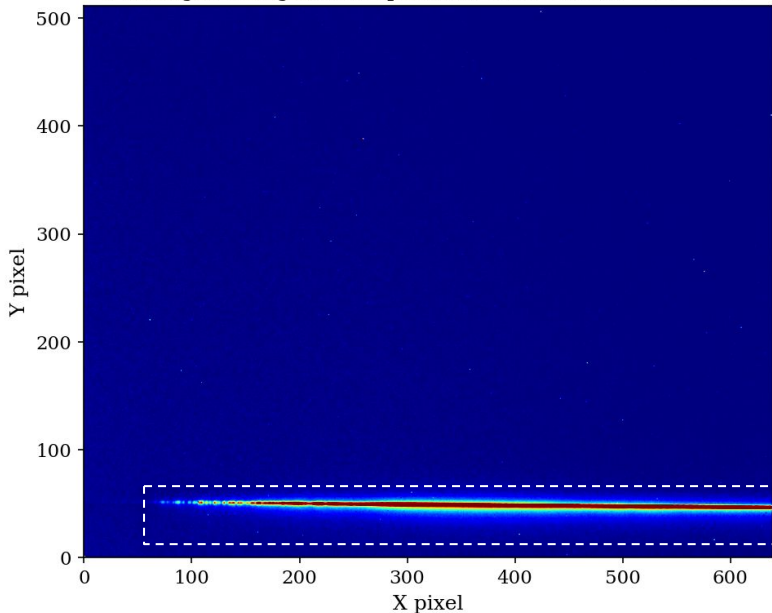
But first without the AWG: straight-through spectra



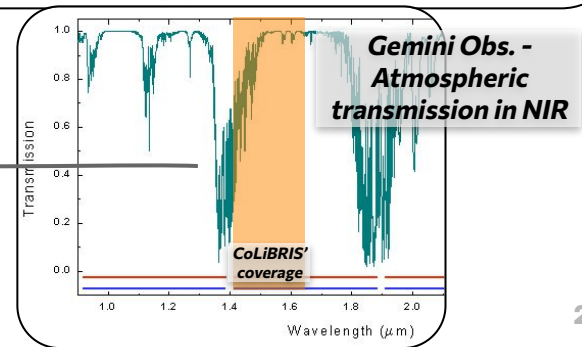
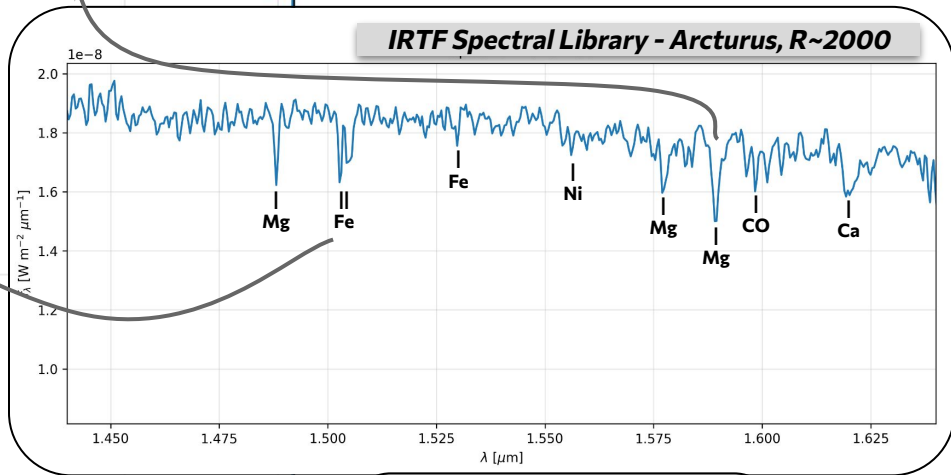
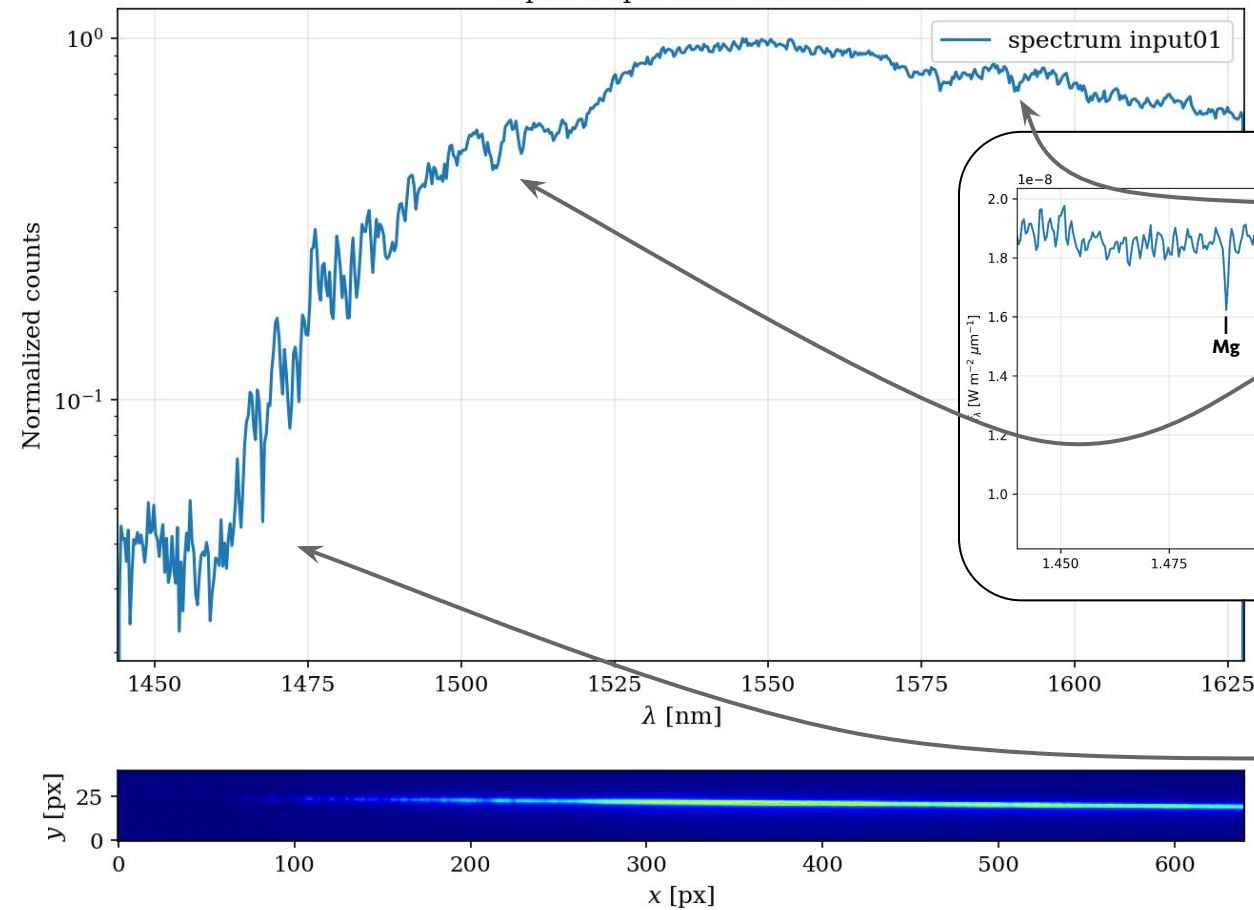
Input01 spectrum: Arcturus



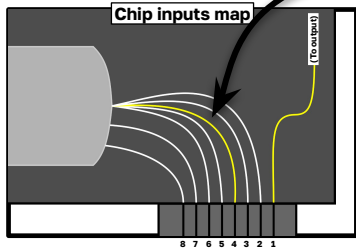
First light straight-thru spectrum of Arcturus 25/02/2026



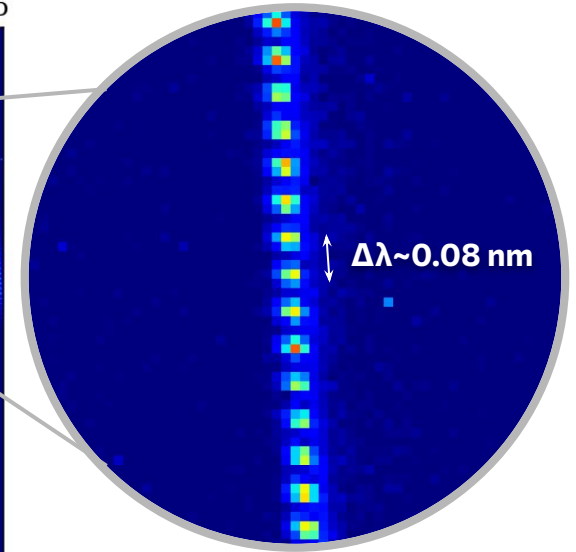
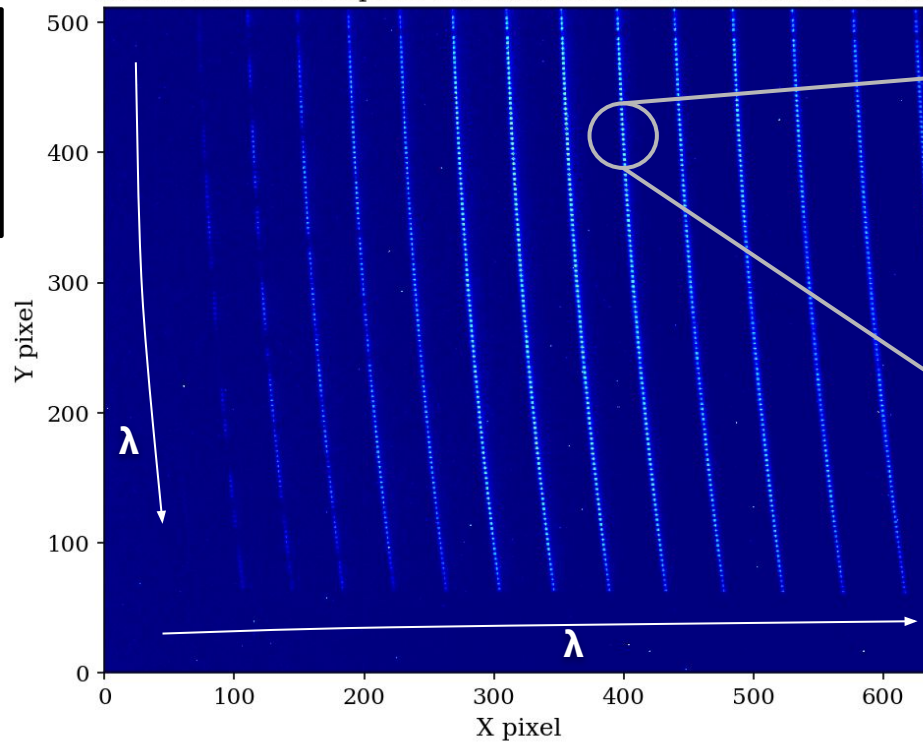
Input01 spectrum: Arcturus



First analysis of the AWG spectra



Mediandcorr. AWG spectrum of Arcturus - 26/02/2026 00-08-95



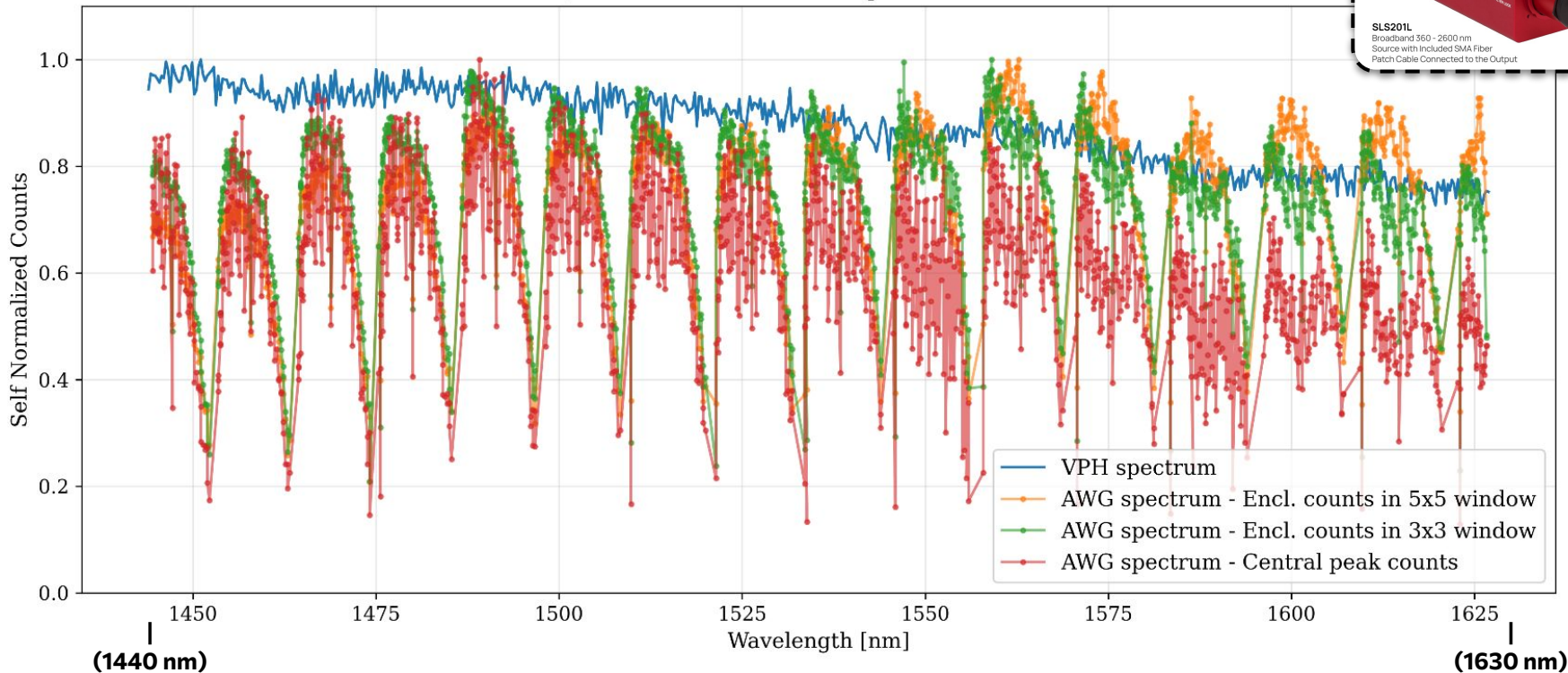
**Spectral Resolution: $R=18800$ at $\lambda=1562 \text{ nm}$
 ($\Delta\lambda$ between 2 adjacent waveguides $\sim 0.08 \text{ nm}$)**

Spectral coverage: 1444 nm to 1630 nm

Instrument response: Broadband source spectra

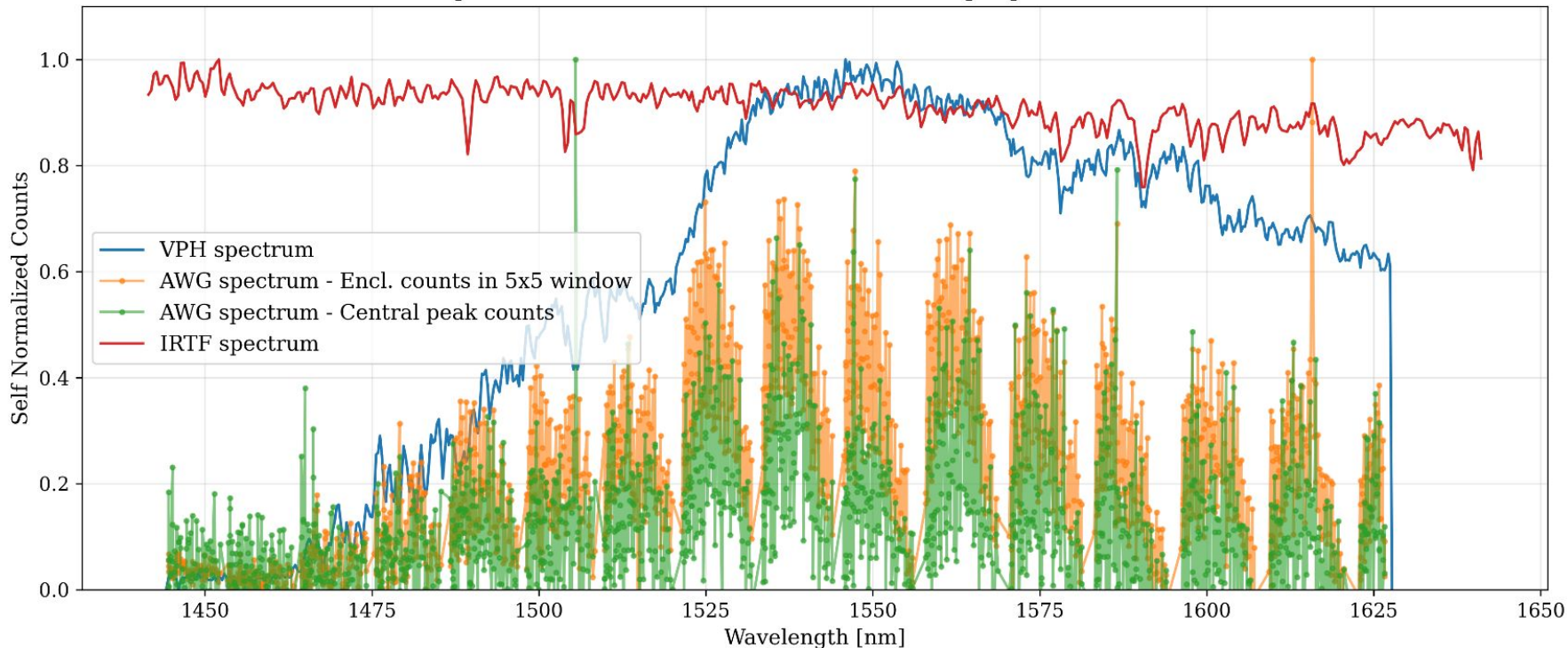


CoLiBRIS/Emerald - Instrument response to broadband source



First extraction of AWG spectra: First light with Arcturus.

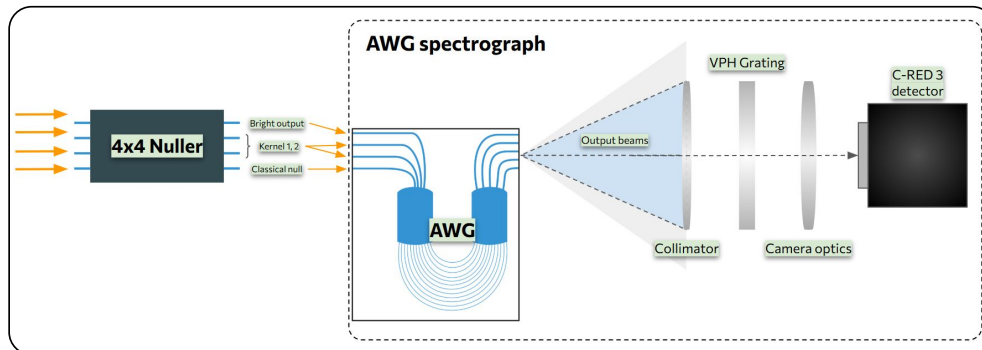
AWG spectrum of Arcturus extracted with bb flat spot positions - no WL cal



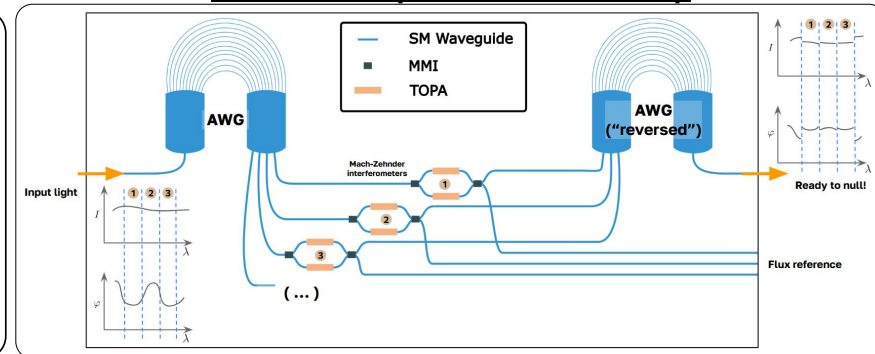
More on-sky testing! Bringing an improved prototype to Calern/AOC, Asiago/Ekarus and other AO capable facilities.

- Cleaner spectral extraction + wavelength calibration & background subtraction.
- Comparison with existing spectra in catalogs (IRTF database).
- Instrument simulation.
- Study improvements for the prototype.
- Future experiments / chip designs involving AWGs and more!

1. Photonic H-band nulling spectro-interferometer



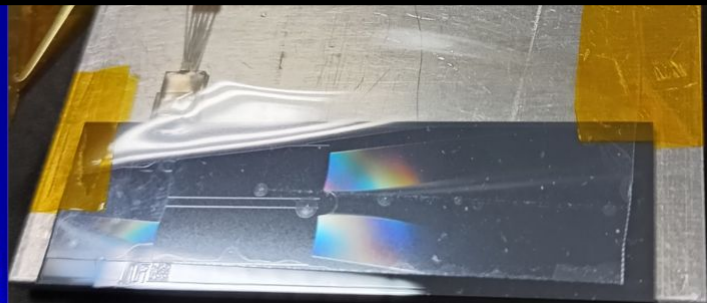
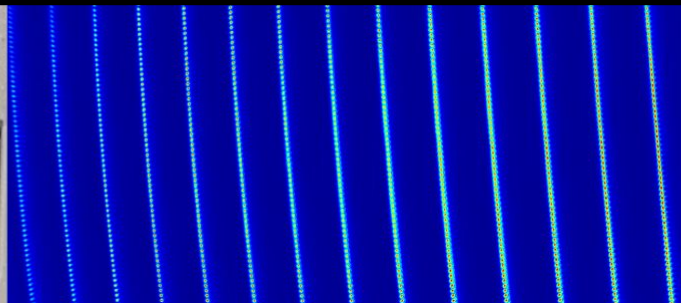
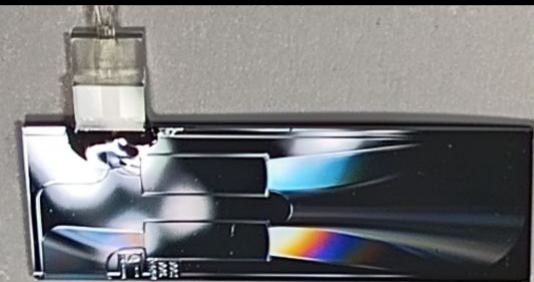
2. Achromatic phase shifter on a chip



Thank you!

jcalderon@oca.eu

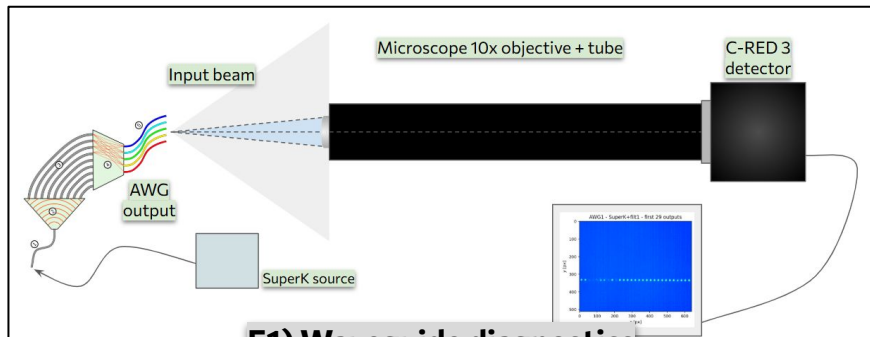
* We acknowledge funding from the project **COMPACT-SPECTROGRAPHS** financed by the **ANR program PEPR Origins (ANR-22-EXOR-0006)**. This work was supported by the **Wilf Family Discovery Fund in Space and Planetary Science**, funded by the Wilf Family Foundation, as well as the support from Keck Institute for Space Studies at Caltech.



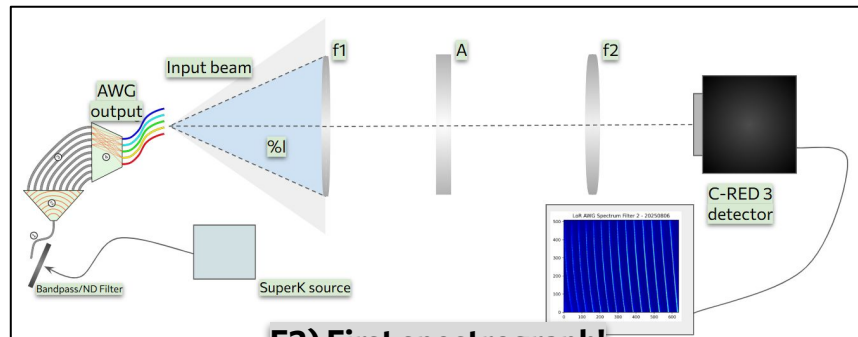
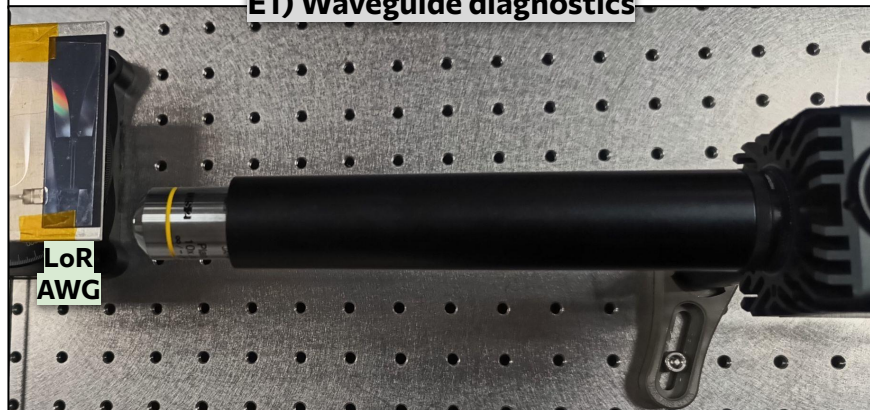
Bonus

Characterization of AWGs

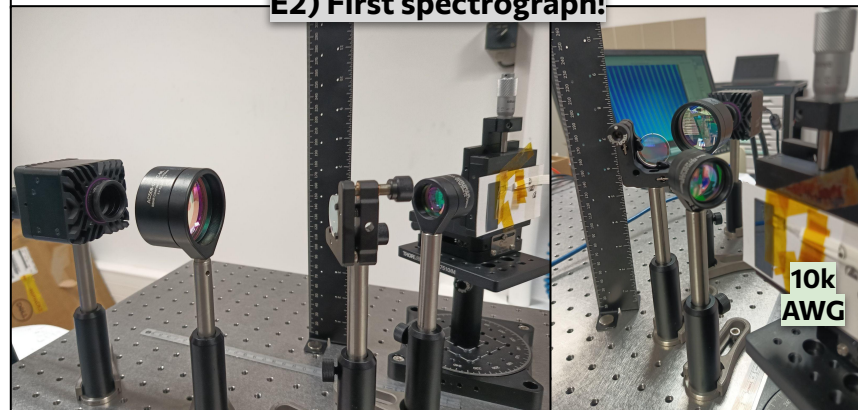
2 experimental setups to characterize the chips (Master's thesis work in 2025):



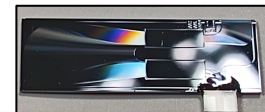
E1) Waveguide diagnostics



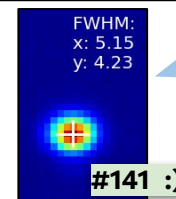
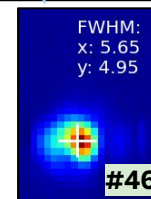
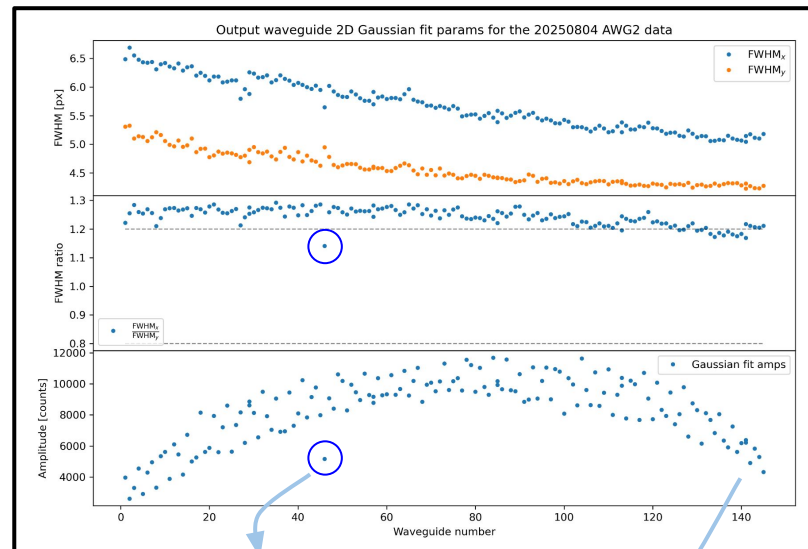
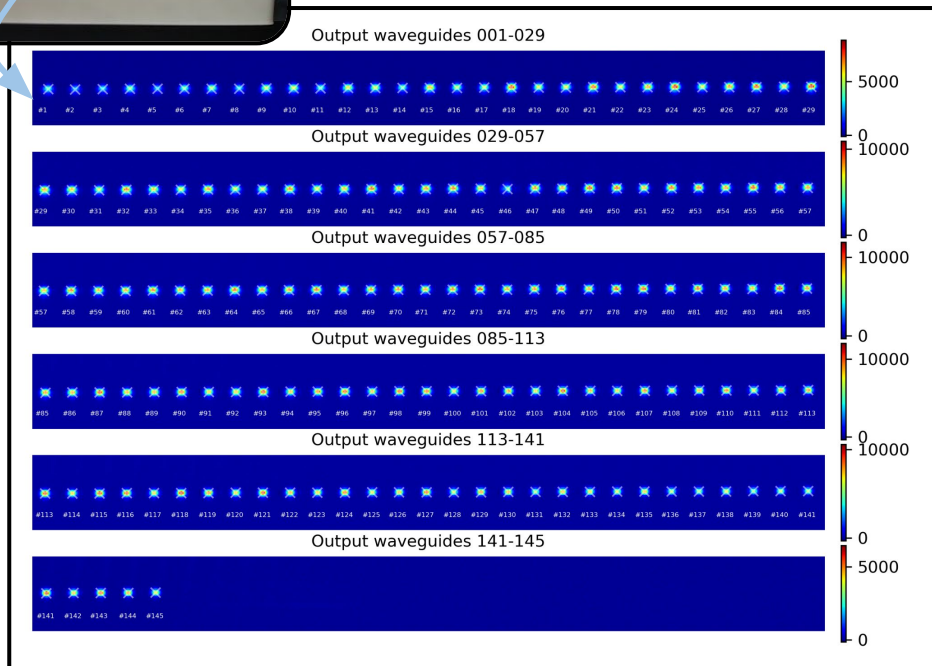
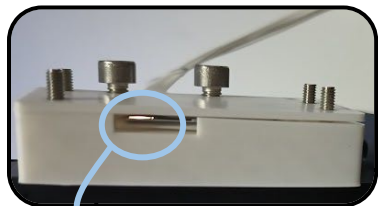
E2) First spectrograph!



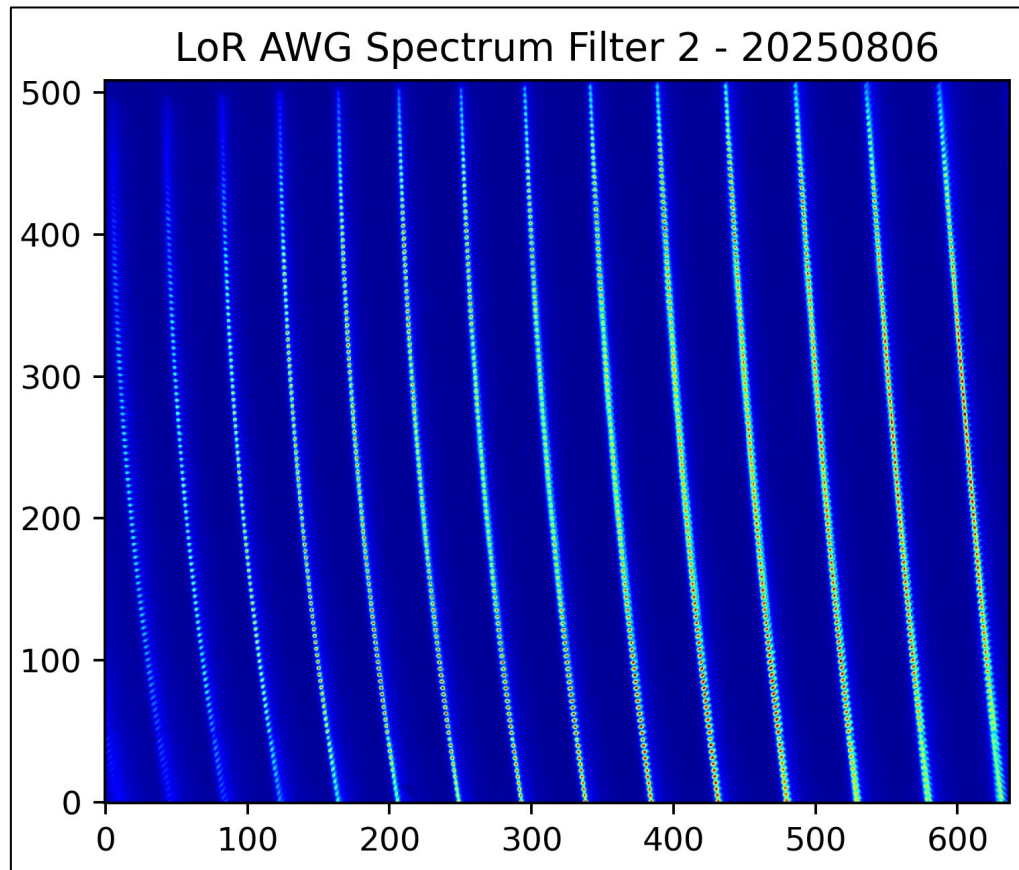
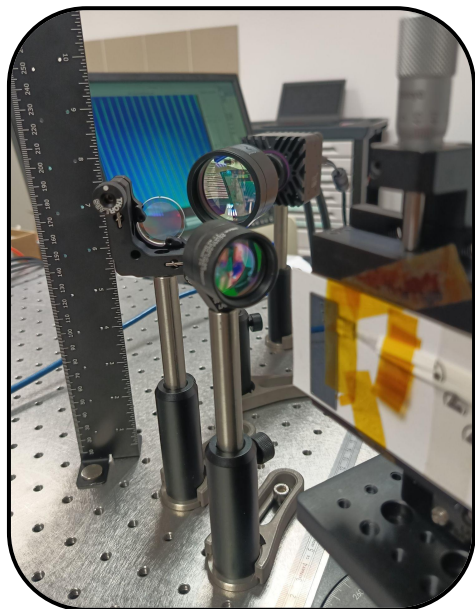
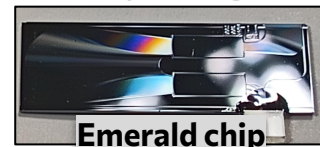
Output diagnostics



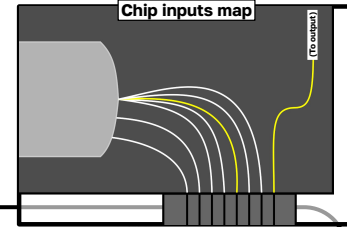
Emerald chip: 145 outputs



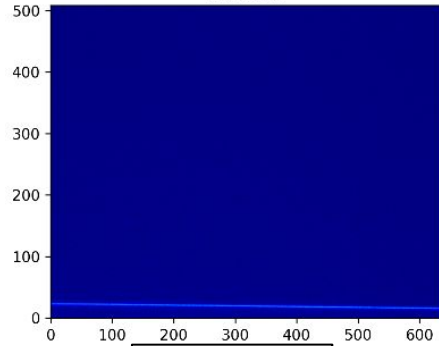
First in-lab spectra with superK laser



Multiple input tests

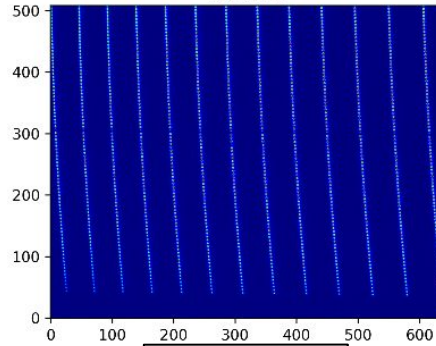


Input 01



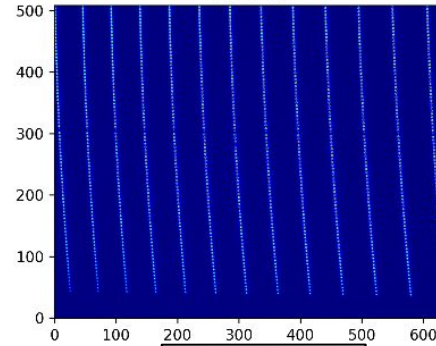
01) Straight-through

Input 02



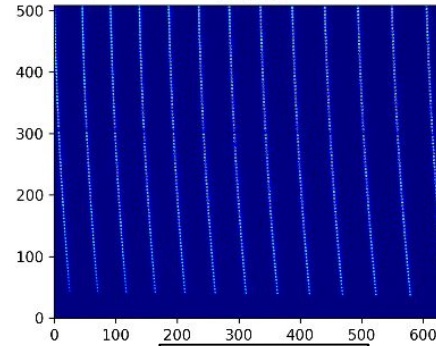
02) AWG - On-axis inj.

Input 03



03) AWG - On-axis inj.

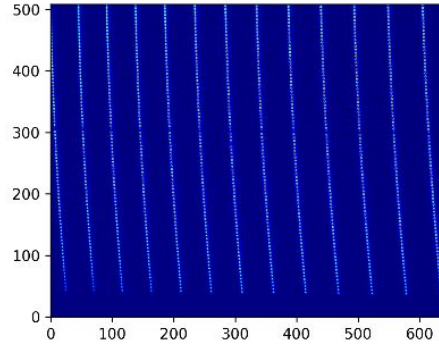
Input 04



04) AWG - On-axis inj.

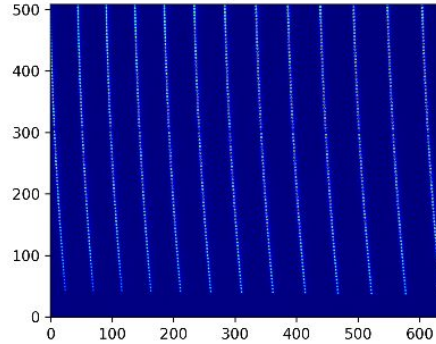
05) AWG - On-axis inj.

Input 05



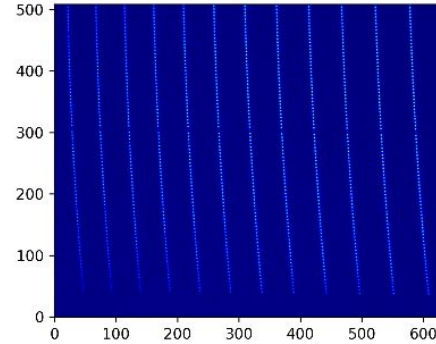
06) AWG - On-axis inj.

Input 06



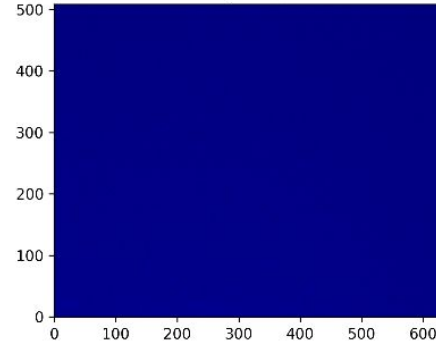
07) AWG - Off-axis inj. (1 FSR offset)

Input 07

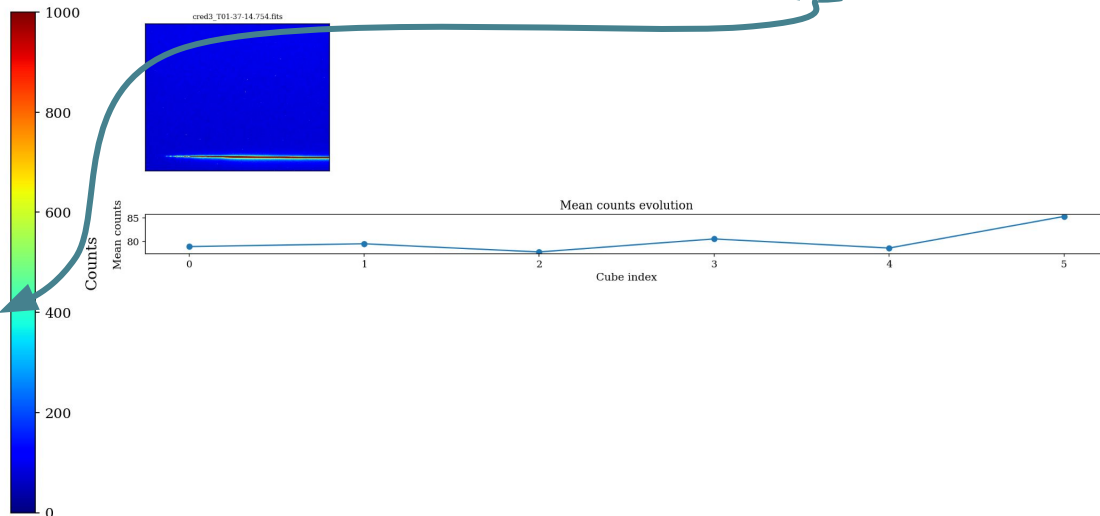
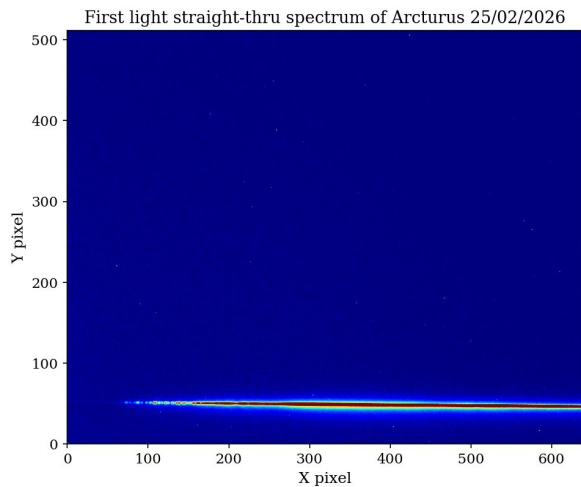
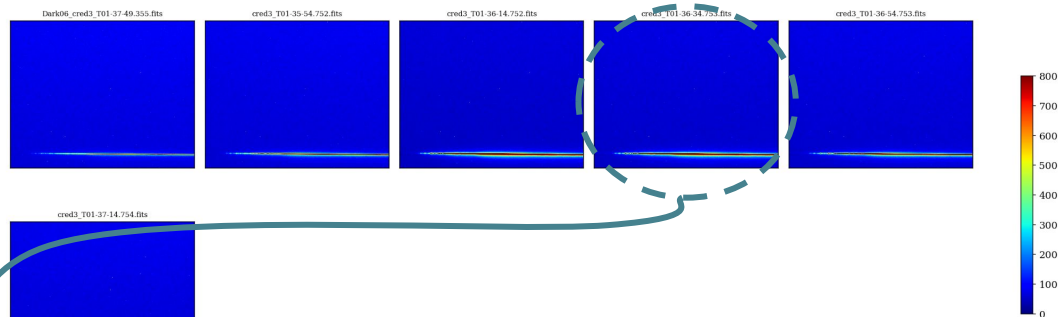


08) AWG - Highly off-axis inj. (no signal)

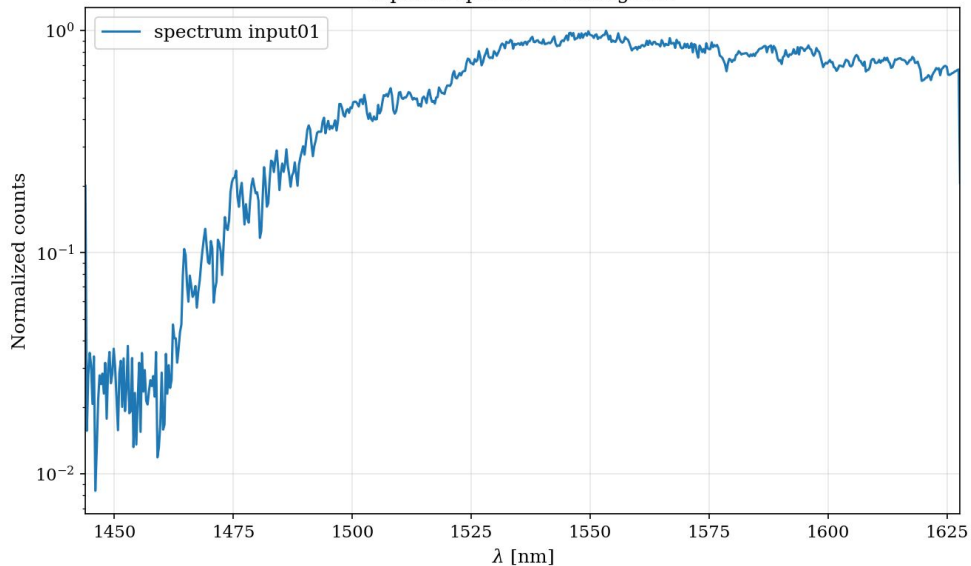
Input 08



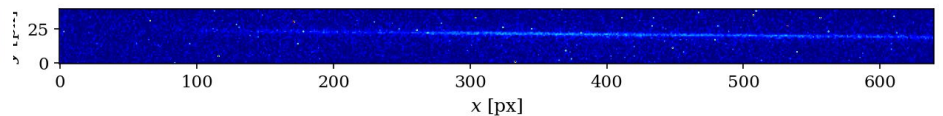
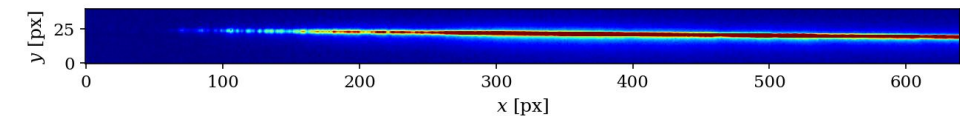
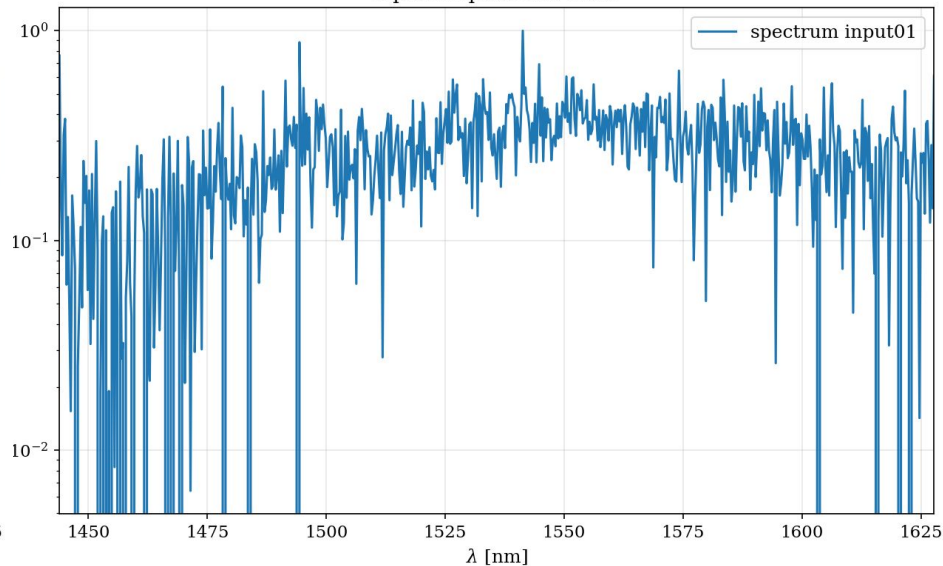
Arc06: Coadded-Dedarkened cubes (20s each) for input01 spectra of Arcturus 20260225



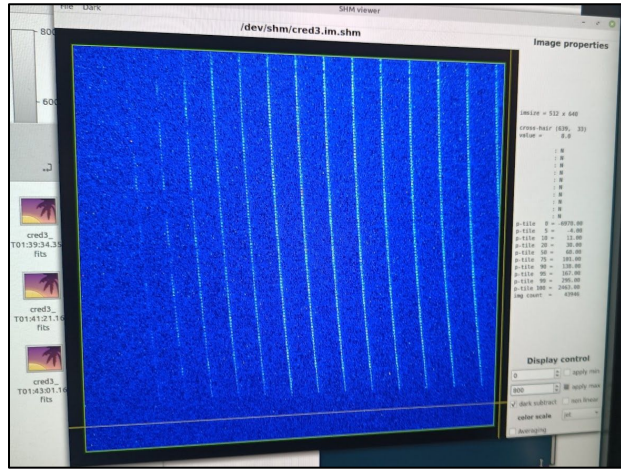
Input01 spectrum: Betelgeuse



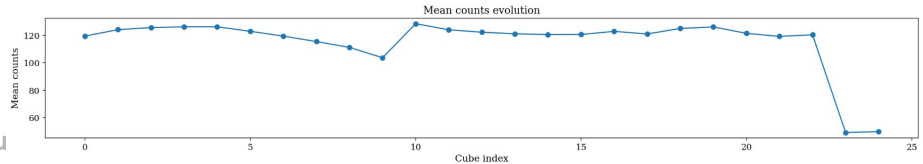
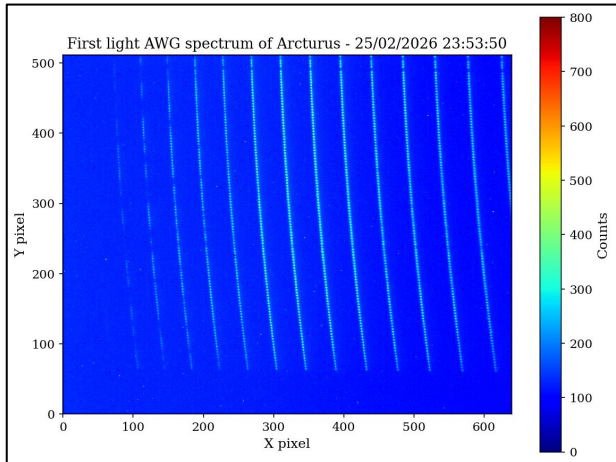
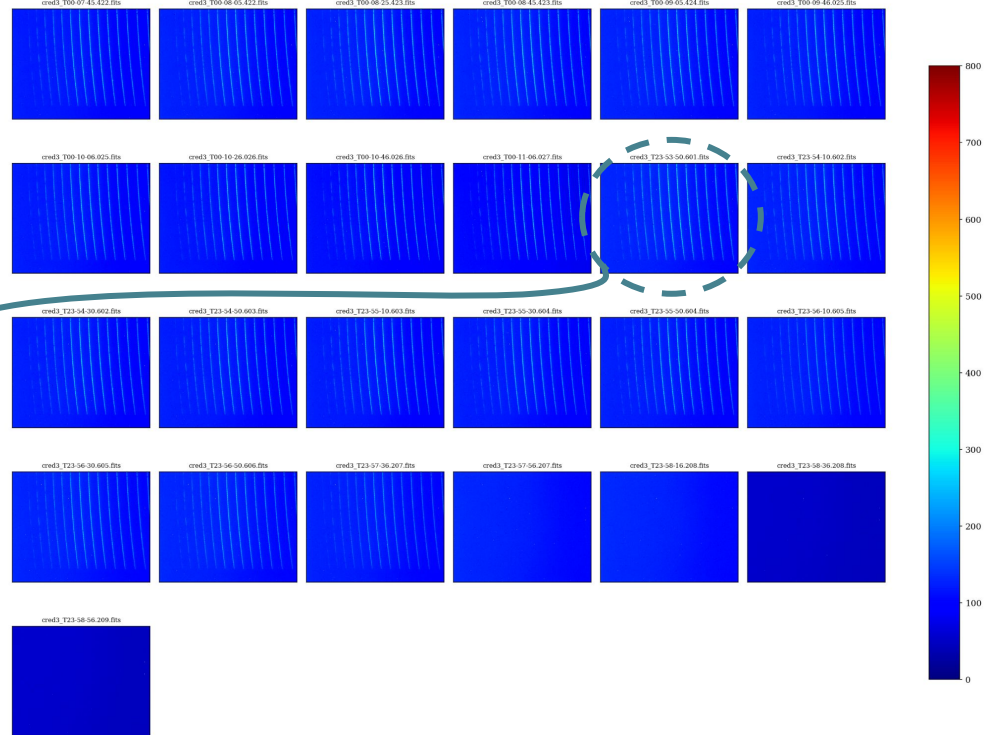
Input01 spectrum: Alcor



AWG First light: 25/02/2026



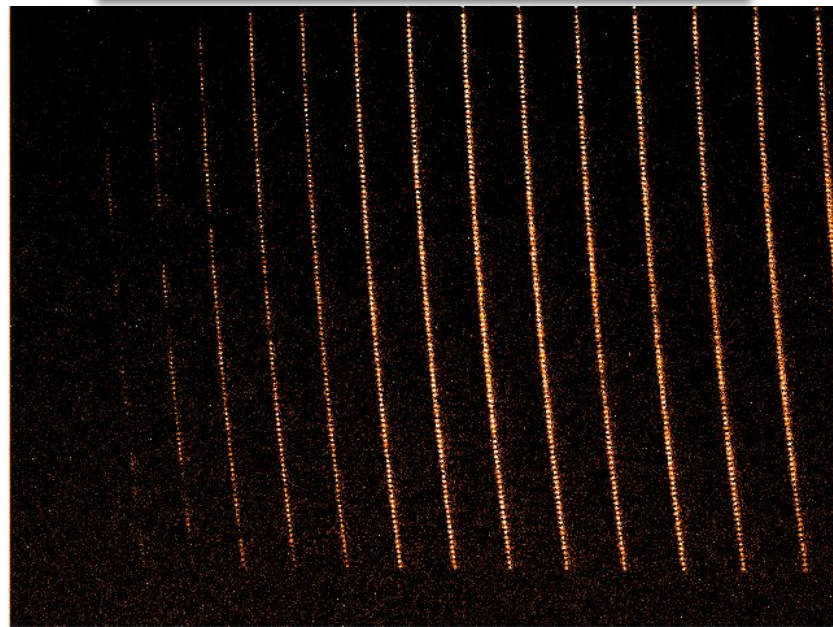
Coadded-Dedarkened cubes (20s each) for input04 spectra of Arcturus 20260225



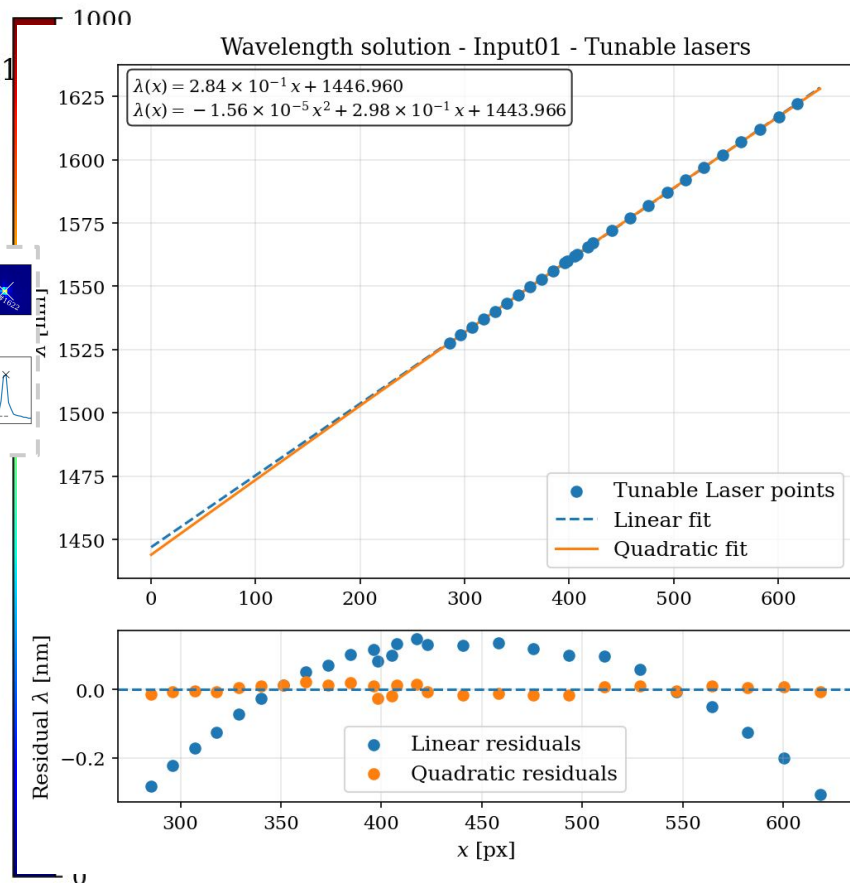
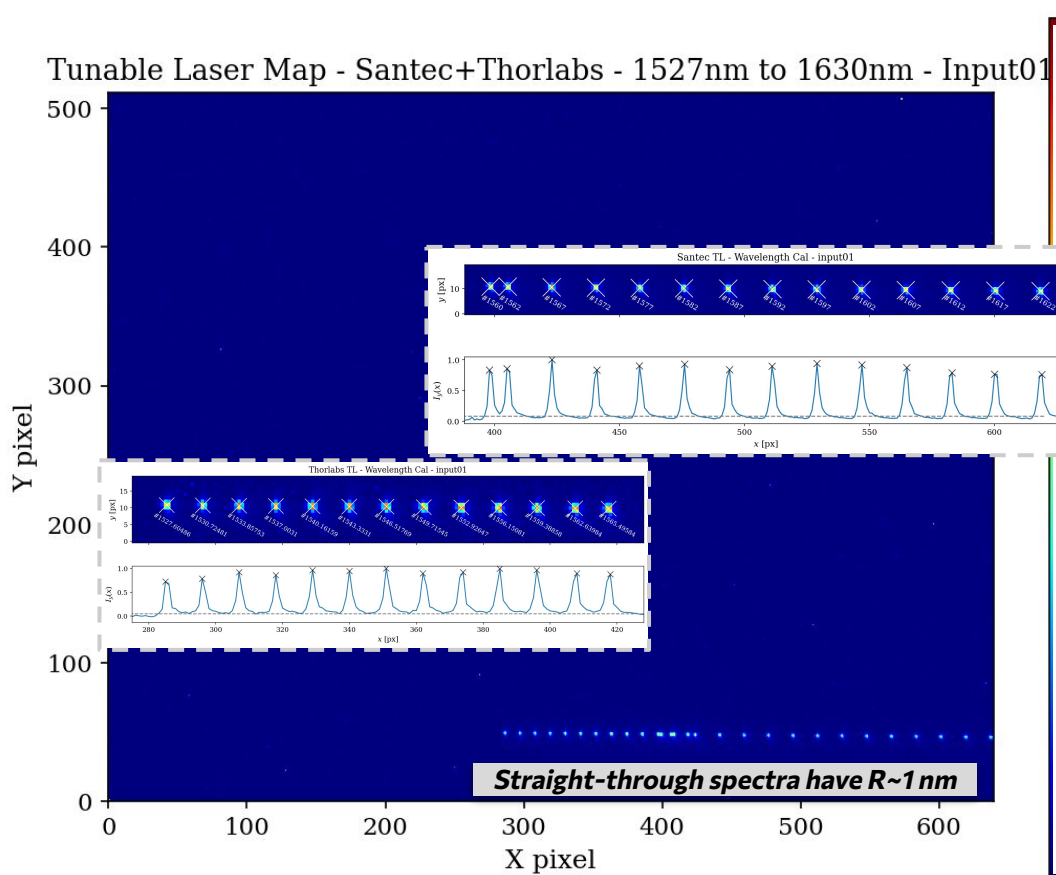
Night 1 attempts at Betelgeuse

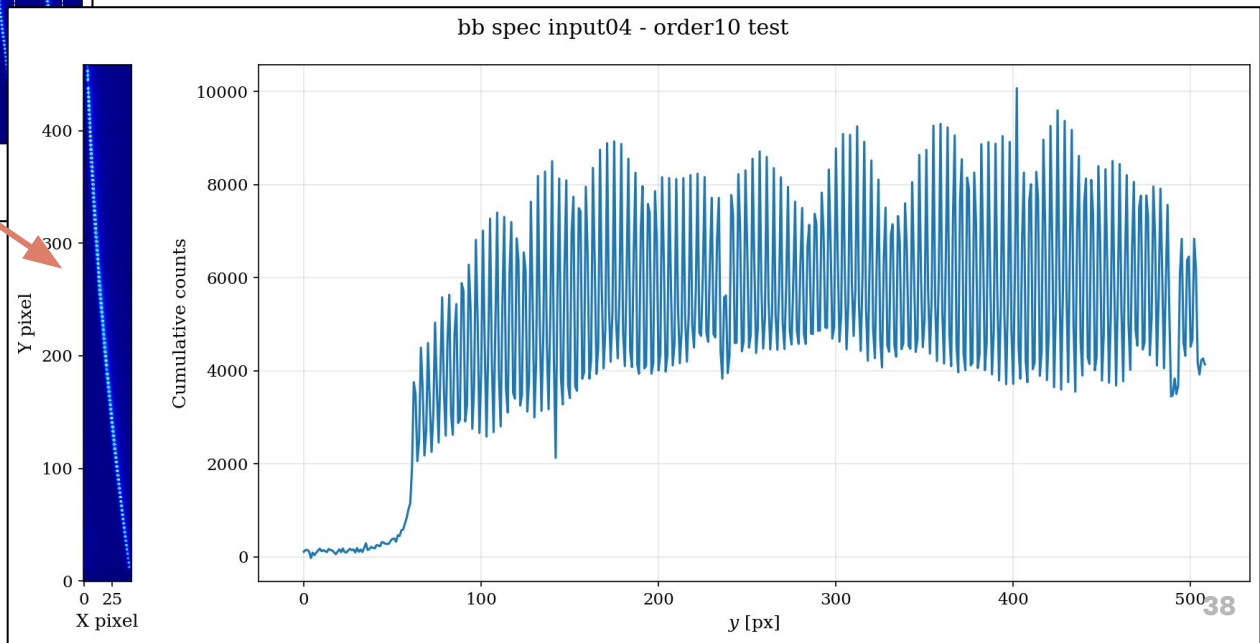
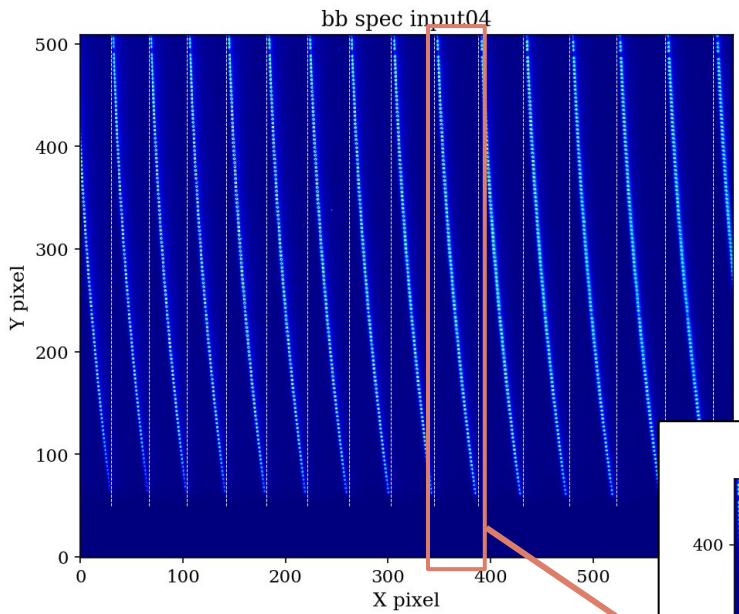


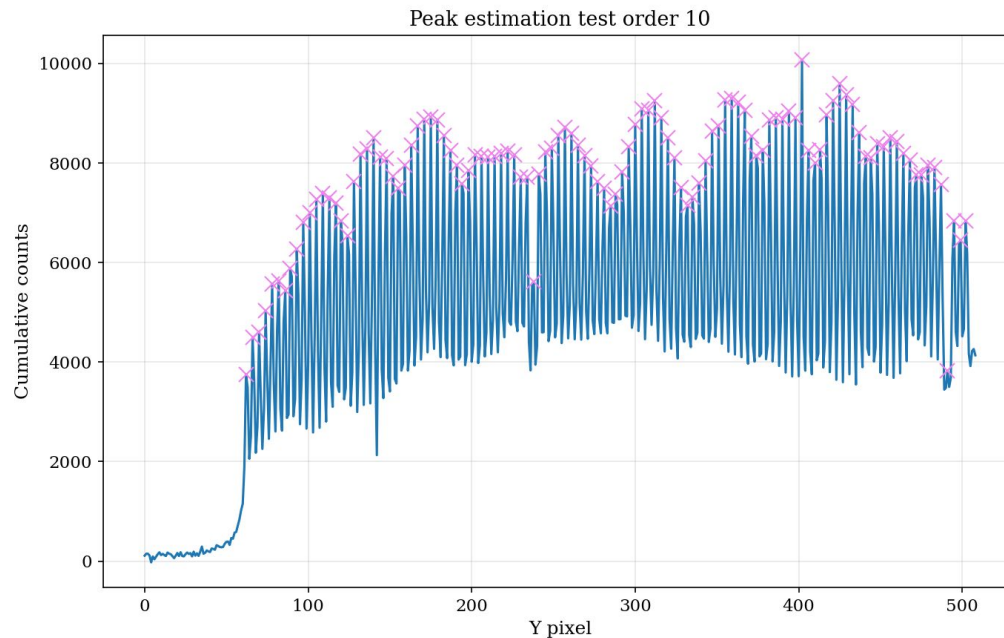
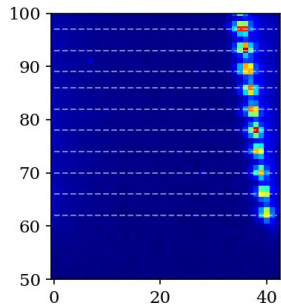
Night 3 Betelgeuse nicer SNR :)



Wavelength calibration: Straight through (no AWG)

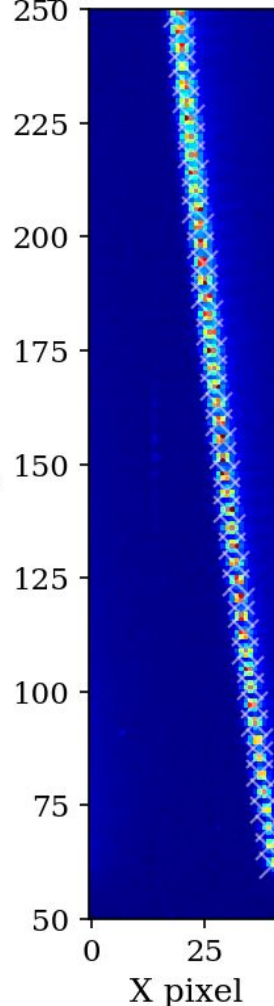






AWG spectrum - bb source

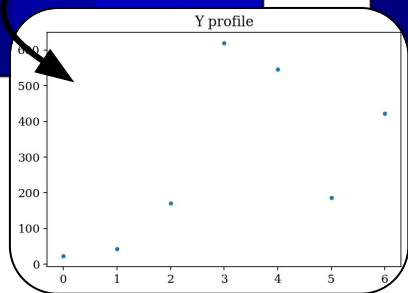
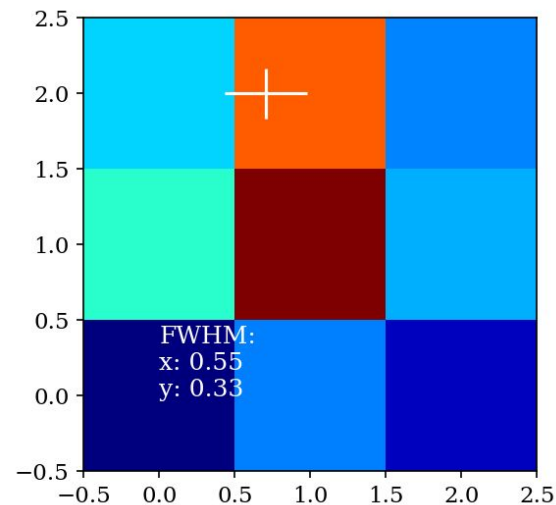
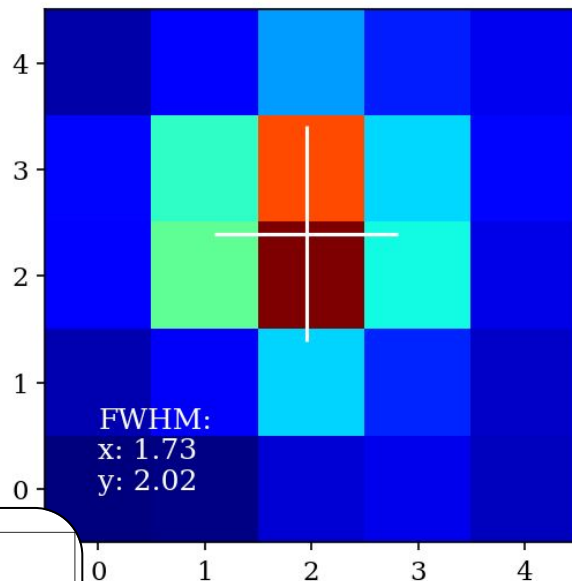
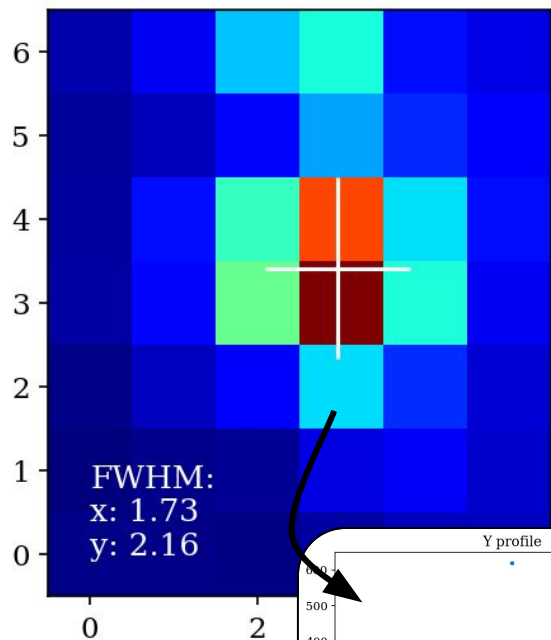
Y pixel



X pixel

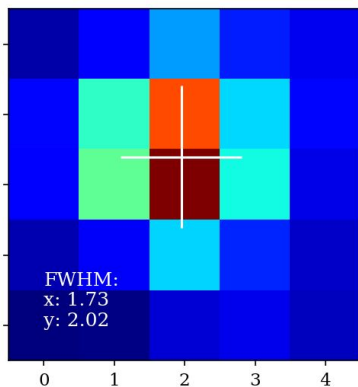
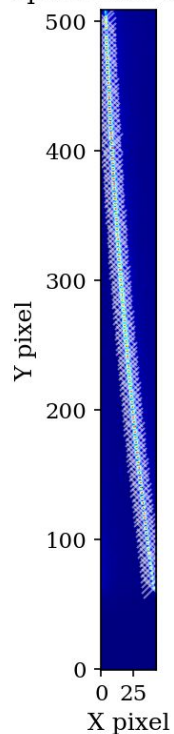
Effects of using a different window size around the spot

AWG spectrum - broadband source

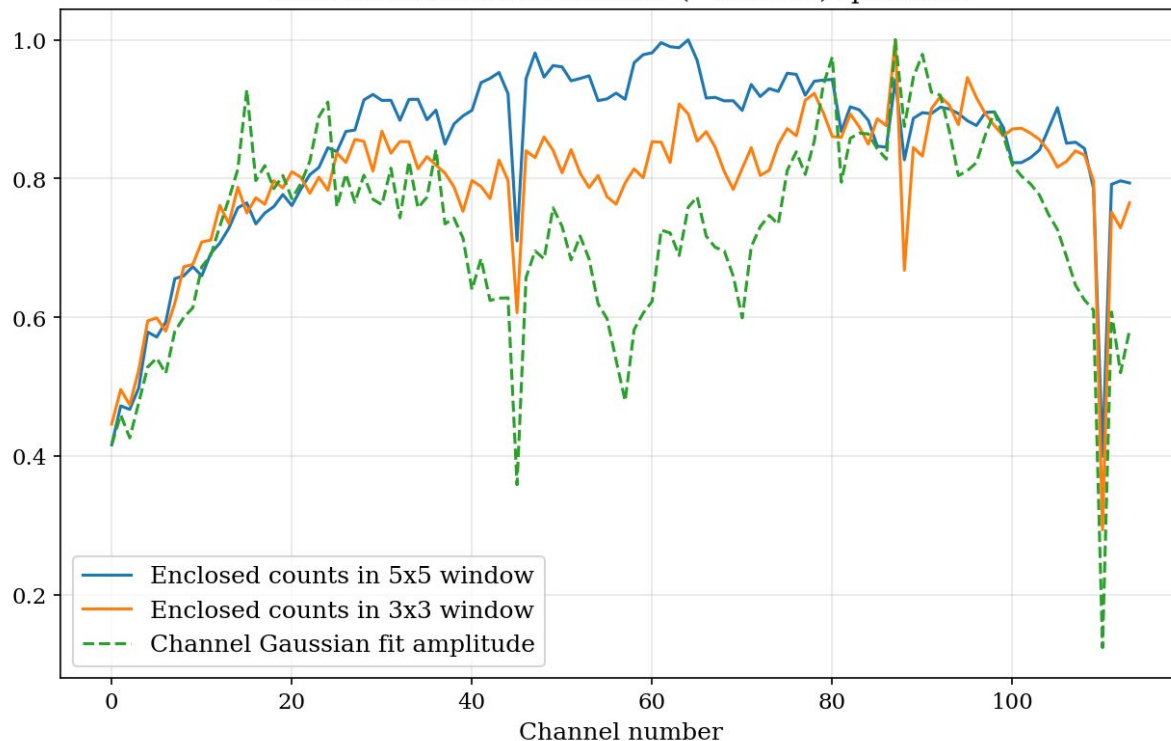


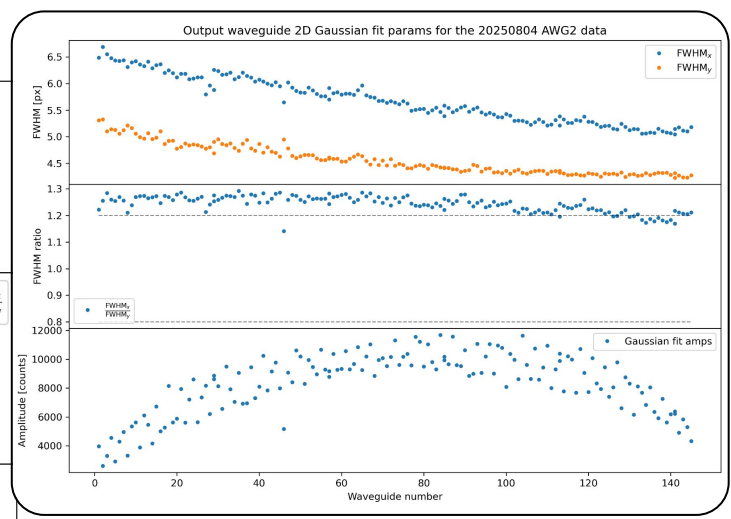
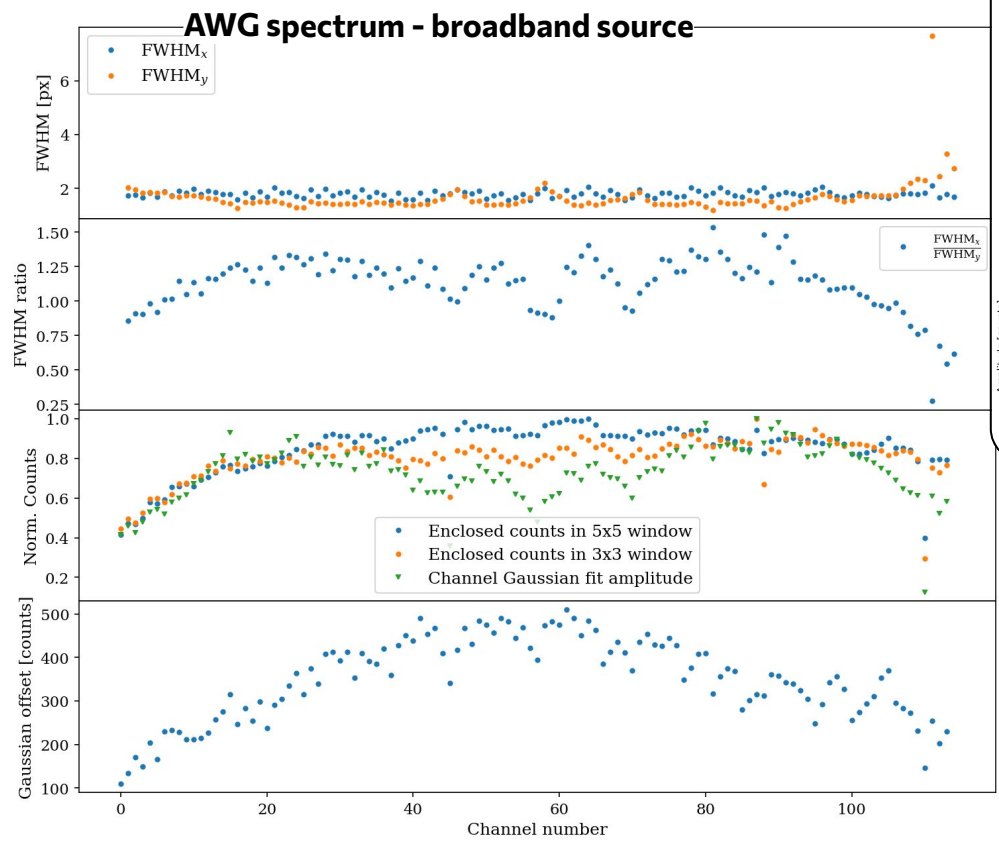
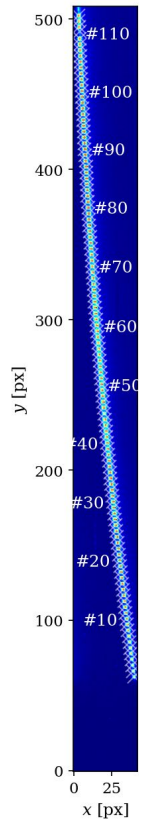
Spectrum of a single order - first extraction

Spot finder Ord10



First extraction AWG Order10 (~1555nm) spectrum

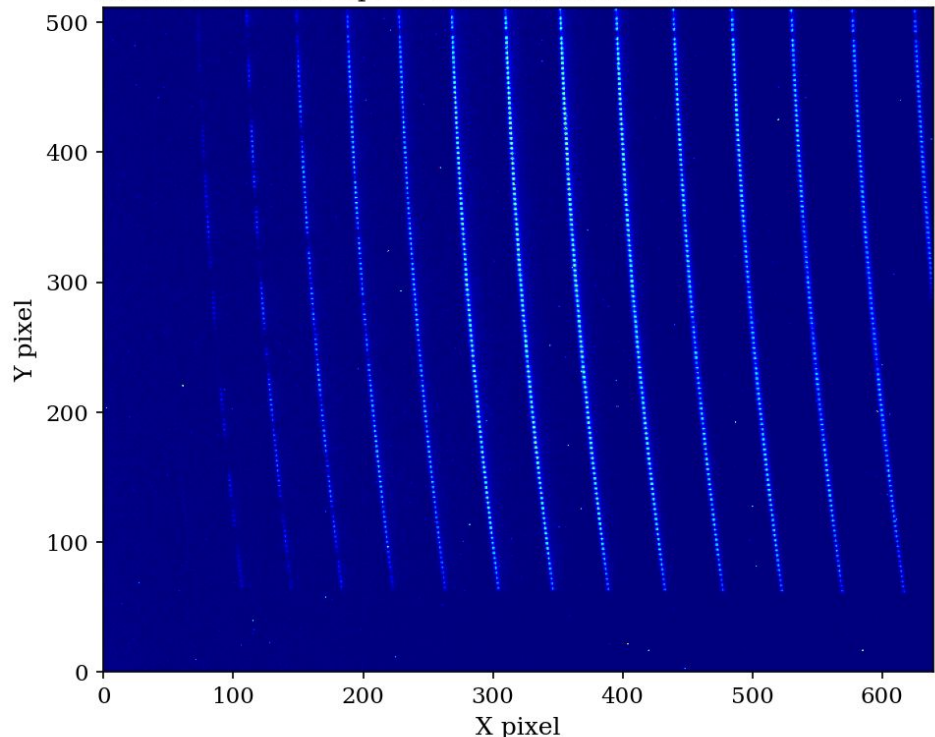

AWG spectrum - broadband source



Throwback to the first characterisation of the chip in Aug/2025

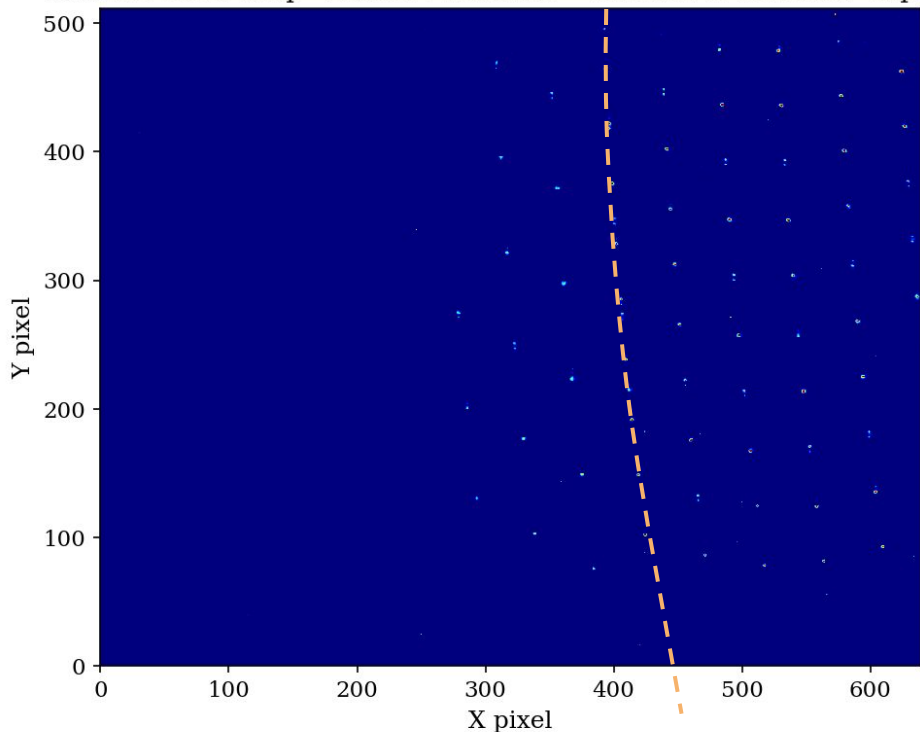
The AWG spectra are kinda tricky to analyze

Mediancorr. AWG spectrum of Arcturus - 26/02/2026 00-08-95



Spectral Resolution: $R=18800$ at $\lambda=1562$ nm
($\Delta\lambda$ between 2 adjacent waveguides ~ 0.083 nm)

Tunable Laser Map - Santec+Thorlabs - 1527nm to 1630nm - Input0

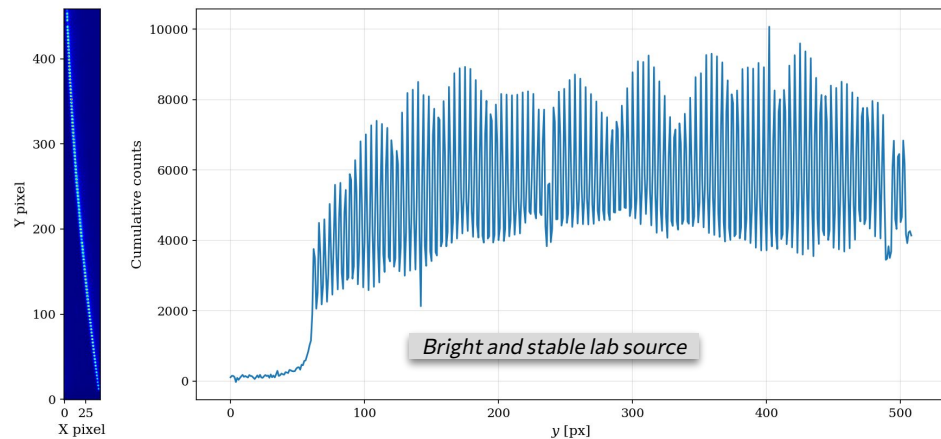


Spectral coverage: 1444 nm to 1630 nm

Lab vs on-sky

Noisy data is making challenging to extract a clean spectrum

bb spec input04 - order10 test



Betelgeuse spec input04 - order5 test

