

# On-sky demonstration of VIPA high resolution spectrometry for exoplanets

A. Carlotti<sup>1</sup>, S. Martos<sup>1</sup>, D. Mouillet<sup>1</sup>, J.J. Correia<sup>1</sup>, S. Curaba<sup>1</sup>, M. Ferlet<sup>1</sup>, A. Delboulbé<sup>1</sup>, A. Alagao<sup>2</sup>, A. Striffling<sup>2</sup>, R. Fétick<sup>3</sup>, J.-F. Sauvage<sup>3</sup>, V. Chambouleyron<sup>2</sup>, B. Neichel<sup>2</sup>, L. Gluck<sup>1</sup>, M.H. Sztfeek<sup>1</sup>, L. Michaud<sup>1</sup>, F. Huppert<sup>4</sup>, F. Dolon<sup>4</sup>.

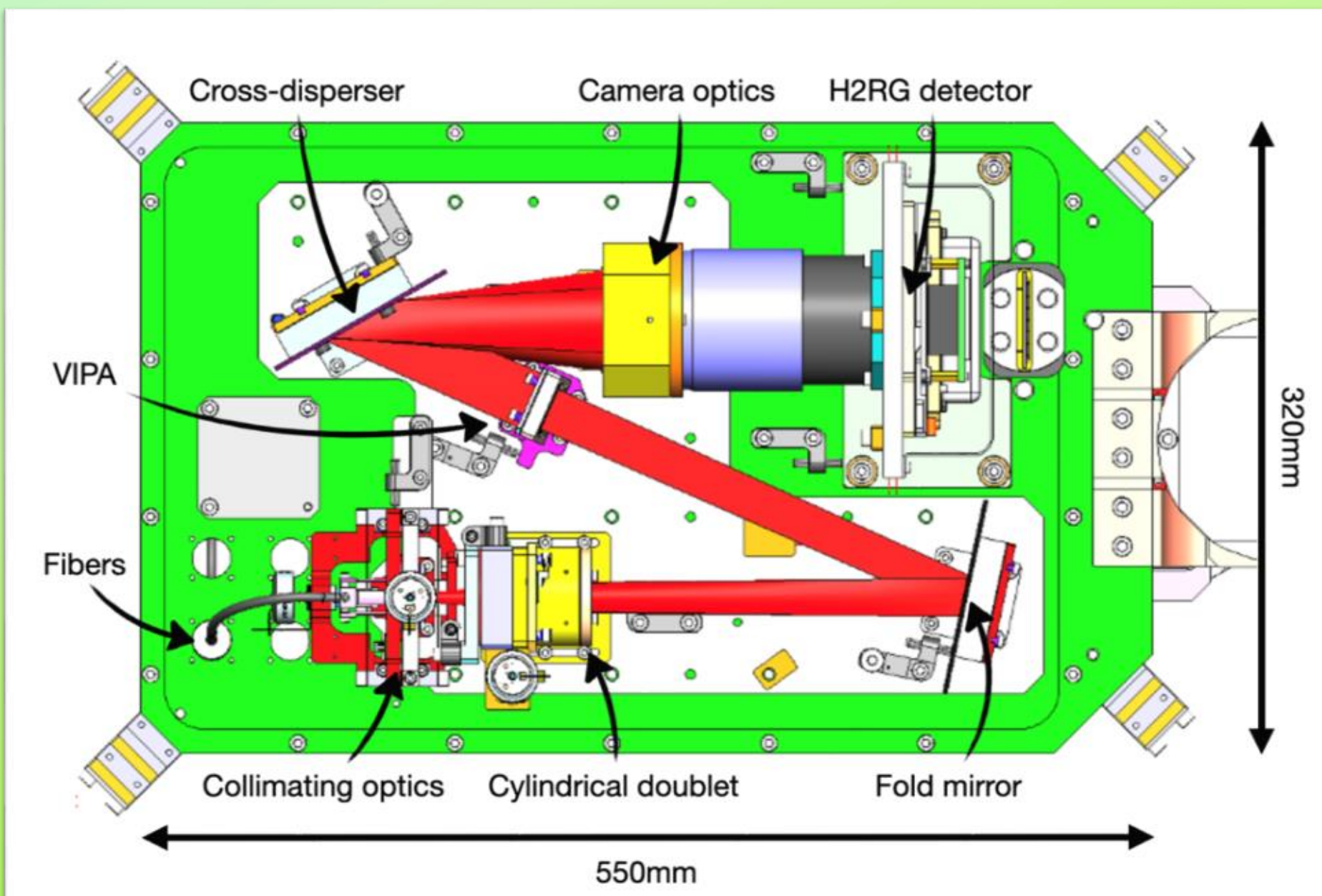
1: Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France ; 2: Aix-Marseille Univ., CNRS, CNES, LAM, Marseille, France ; 3: DOTA, ONERA (France); 4: UAR Pytheas - OHP

## Exoplanets & high-res spectroscopy: a love story

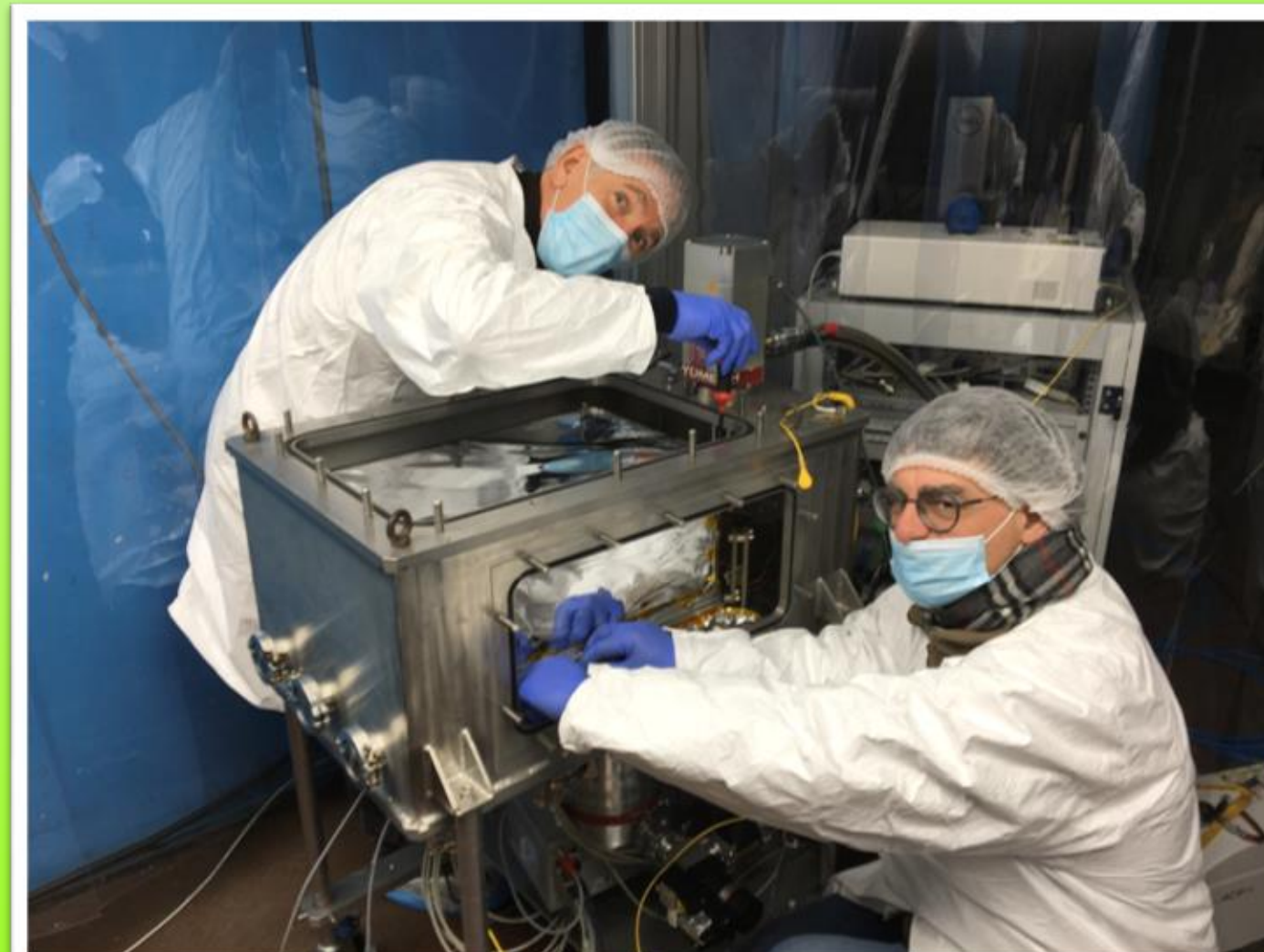
HR spectrometers are a key element in radial velocity, transit spectroscopy, and, more recently, angularly resolved atmosphere characterization with XAO-assisted instruments (KPIC, Mawet+ 2017; SPHERE/HIRISE, Vigan+ 2022; RISTRETTO, Lovis+ 2022). In that case, the global transmission is only 2-4%. **The efficiency of spectrometers is one of their main limitations** (ex: ~20% with CRIRES+). A higher efficiency will be needed by future instruments such as the **ELT Planetary Camera and Spectrograph (PCS)**. Working in a diffraction-limited regime is another evolution to consider: contrary to the seeing-limited case, the size of the dispersing element does not scale with the telescope diameter (200mm long with CRIRES+ means ~1m for ELT).

## The VIPA H/K band spectrometer

Following a 1<sup>st</sup> VIS prototype (Bourdarot+ 2017), we initiated in 2018 an R&D project that uses a **Virtually Imaged Phased Array (VIPA, Shirasaki+ 1996)** as an échelle grating in a **very compact** (<<1m<sup>3</sup>), high resolution, **R~80000**, échelle-like spectrometer, specifically designed to **characterize diffraction-limited sources with a 40% efficiency**. RV stability was **not** a requirement. A **NIR demonstrator** (funded by the LabEx OSUG & FOCUS, the ERC EXACT, and the PEPR ORIGINS/C-SPEC) was first tested at the Hale telescope at **Palomar** (Carlotti+ 2022) before a **science grade H2RG detector** was obtained and integrated. A **year long series of observations at OHP** with the **PAPYRUS** adaptive optics system (Fétick+ 2024) at the T152 telescope was then completed in 2025 and 2026 to exhaustively study its effective performance on sky.



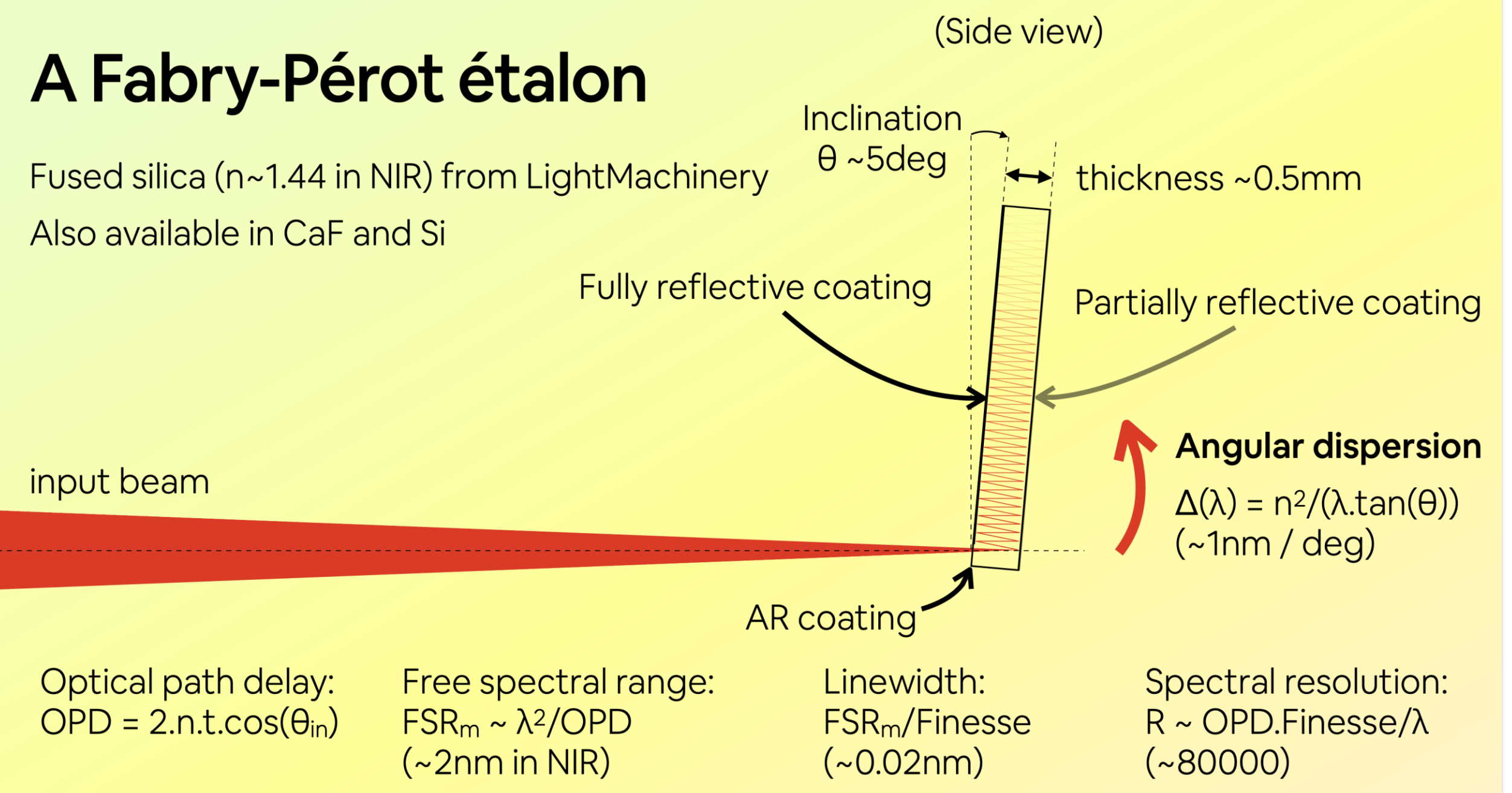
Engineers A. Delboulbé & J.J. Correia installing the NIR demonstrator at OHP in February 2025.



## Virtually Imaged Phased Array's physics

### A Fabry-Pérot étalon

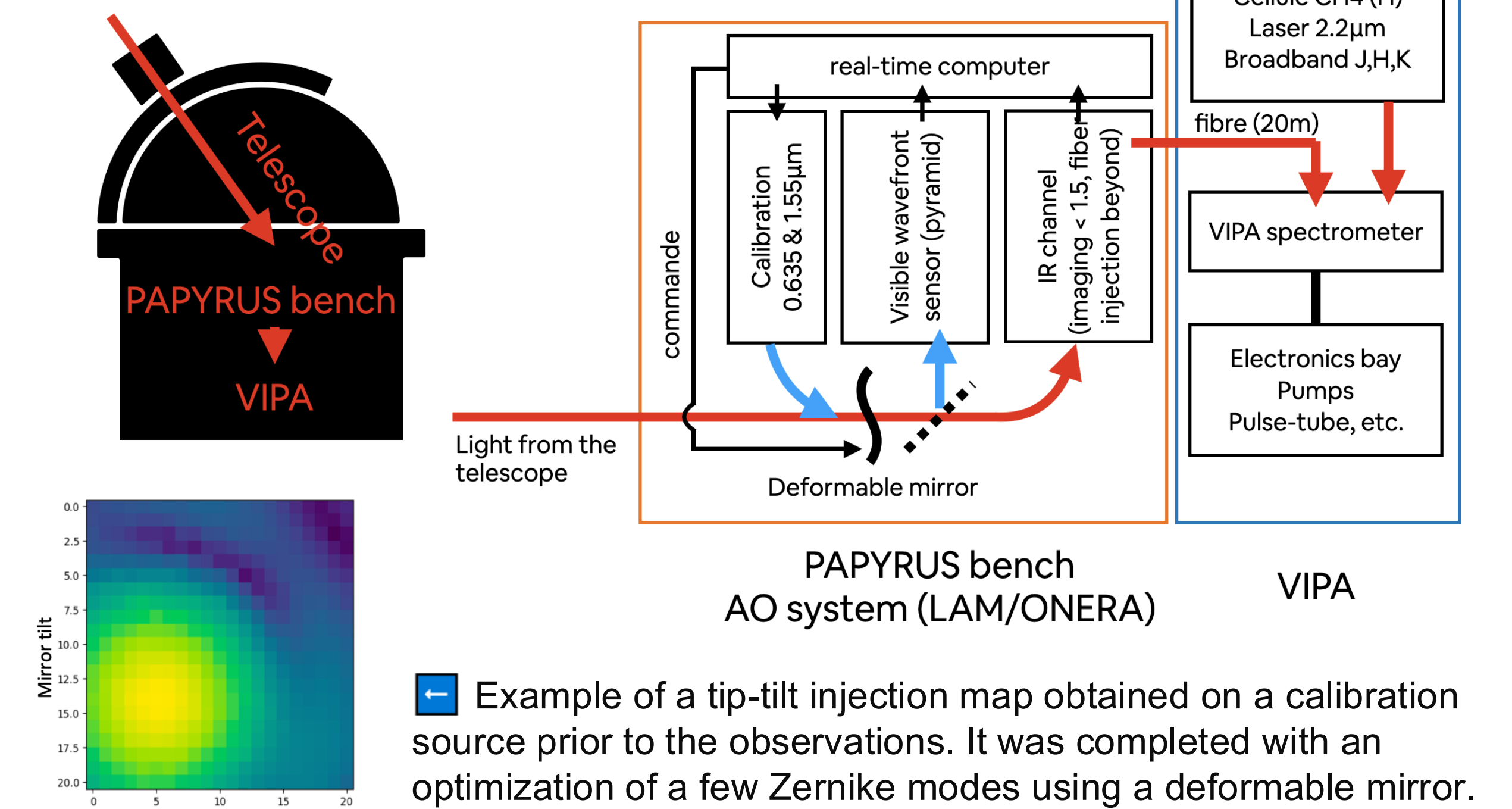
Fused silica (n~1.44 in NIR) from LightMachinery  
Also available in CaF and Si



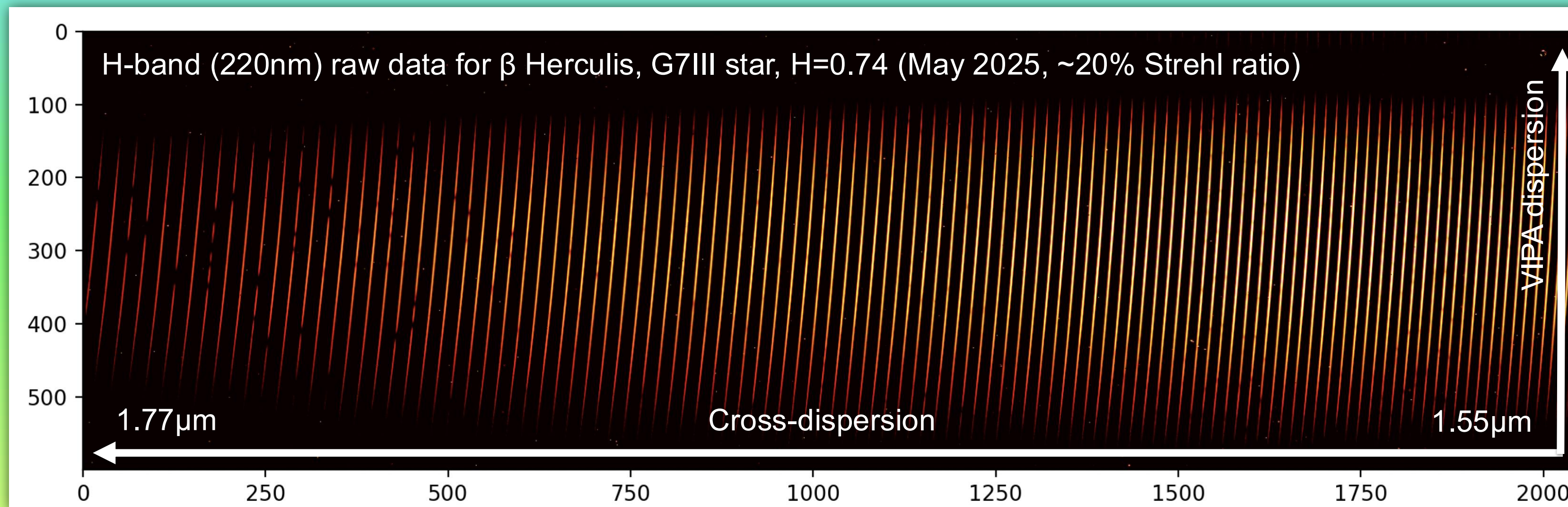
## Injecting light into the instrument

Fiber injection unit added to the PAPYRUS AO system with 37% coupling (TC25APC-1550, triplet). Reflective collimator (RC08APC-P01) provided 28% efficiency (far from 60% theoretical value).

Fiber injection unit uses deformable mirror, tip-tilt mirror, C-RED2 camera, dichroic & corner cube to **align the target onto the fiber, and maximize the injected flux**.



## Data acquisition & reduction pipeline



### Seven observation runs, and many stars observed

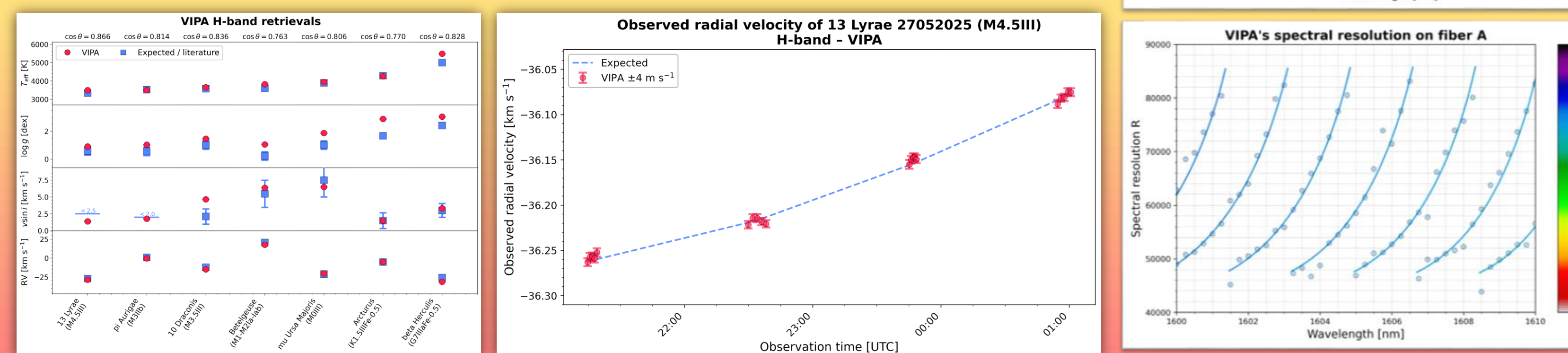
- A & B reference stars, K & M feature rich stars
- RV precision demonstrated with high-RV stars (incl. planets!)
- Resolved binary for astrometric calibration & contamination test

### Calibration procedure and reduction pipeline (S. Martos PhD)

- Orders flat obtained with broadband source
- Spectral calibration with tunable laser, CH4 gas cell, tellurics
- Bad pixels identified (1.5%): hot, dead, or unreliable pixels
- Orders fitted, read, spectrally calibrated, merged into full spectrum
- Data high-pass filtering, and forward modeling using models

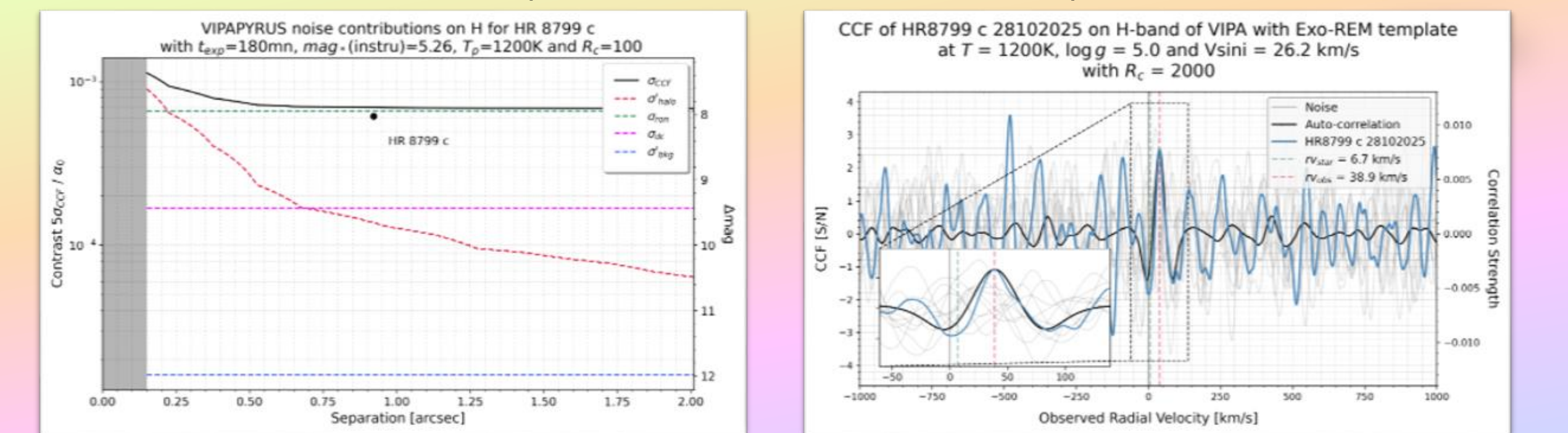
### Performance measured with H-band optics

- Global throughput: 38% (input fiber to, and including the detector)
- Mean spectral resolution *after extraction*:  $R \sim 70000$
- RV precision: down to 4m/s (whole range) *though not designed for*



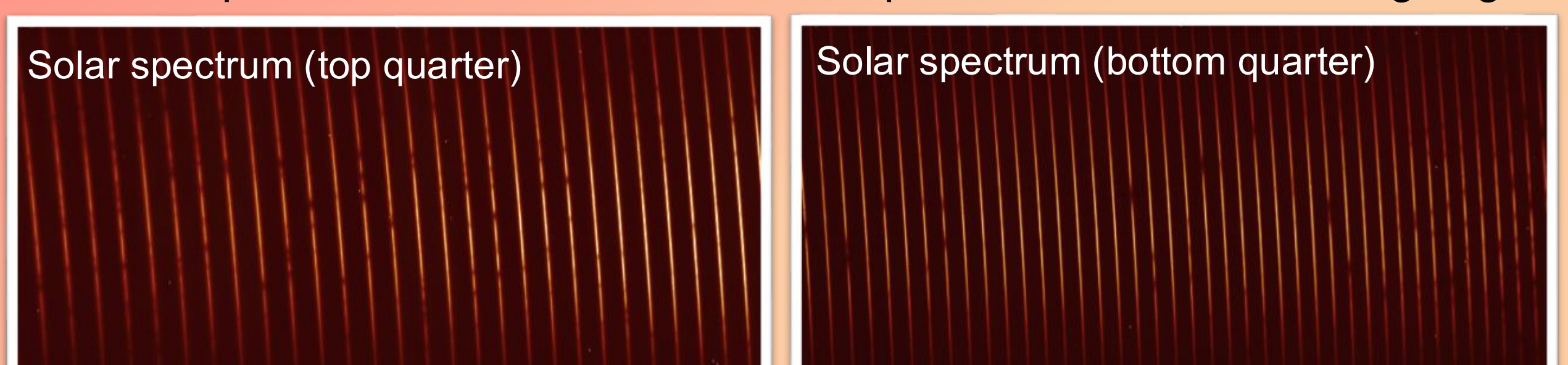
## Attempt at observing HR8799c

- 3h blind tracking of the planet (0.92", i.e. 4M/D) ;  $\sim 30\%$  Strehl
- No confident detection (RON is the main limitation), but close!!!



## Successful K-band demonstration

- On-sky observation (OHP, 03/2026) with expected non-ideal alignment
- Successful alignment in the lab: 2.07-2.31μm spectrum obtained
- Data acquired on the Sun. Reduction & spectral calibration are ongoing.



## Next steps

- 2027: AIT of H+K version (both spectra acquired at the same time)
- Likely participation to whitepapers for the « VLT beyond 2030 » ESO call
- More on-sky observations! Now looking towards 8m telescopes.
- 2028: test of a new HK frequency comb laser (ANR TRACES)

DOI references: Mawet+ 2017, 10.1117/12.2630142 | Lovis+ 2022, 10.1117/12.3020142 | Vigan+ 2022, 10.1051/0004-6361/202348019 | Bourdarot+ 2017, 10.1117/12.2296210 | Shirasaki 1996, 10.1364/OL.21.000366 | Carlotti+ 2022, 10.1117/12.2628937 | Fétick+ 2024, 10.1117/12.3019758