CRIRES+
at the Very Large Telescope

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at the Very Large Telescope

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Summary

CRIRES+ is a:

- adaptive optics fed **high-resolution** ($R \sim 10^5$) near-IR slit **spectropolarimeter**
- located at Nasmyth focus of 8-m VLT UT 3
- wavelength range 950 → 5200 nm (spectroscopy) | 950 → 2500 nm (polarimetry)
- **Now with a cross-dispersed** spectrograph: larger spectral grasp

CRIRES+ works in regular operations since october 2021.
Public data (**raw**) has started to appear on the archive (1-year proprietary period).
CRIRES+ has **several acquisition/observing modes**: read the manual and play with ETC

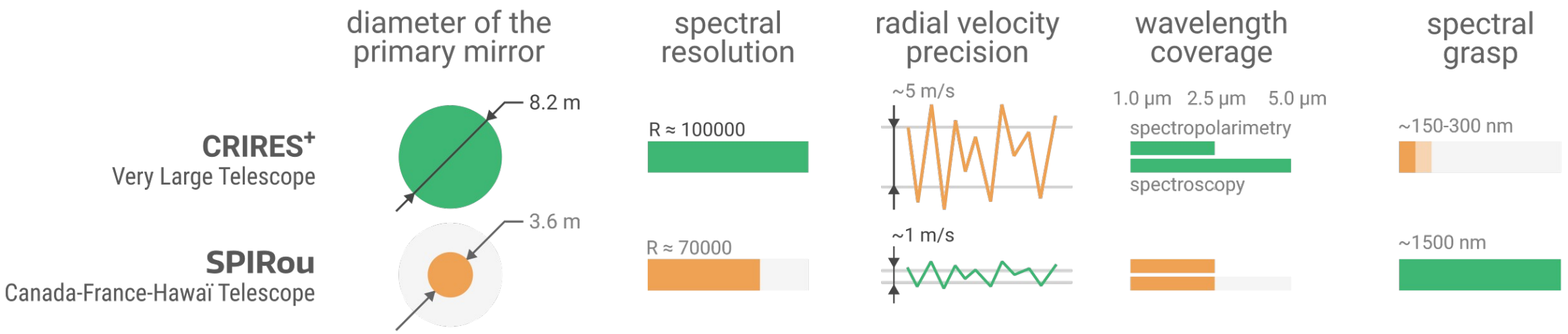
Useful CRIRES+ resources

- CRIRES+ page at ESO
- CRIRES+ A&A paper (Dorn et al. 2023)
- User manual
- Exposure time calculator
- ESO Call for Proposals
- CRIRES specific ESO data archive
- astroquery.eso
- CR2RES DRS installation & manual (`CRIRES` is the pipeline for the old CRIRES. **`CR2RES`** for CRIRES+)

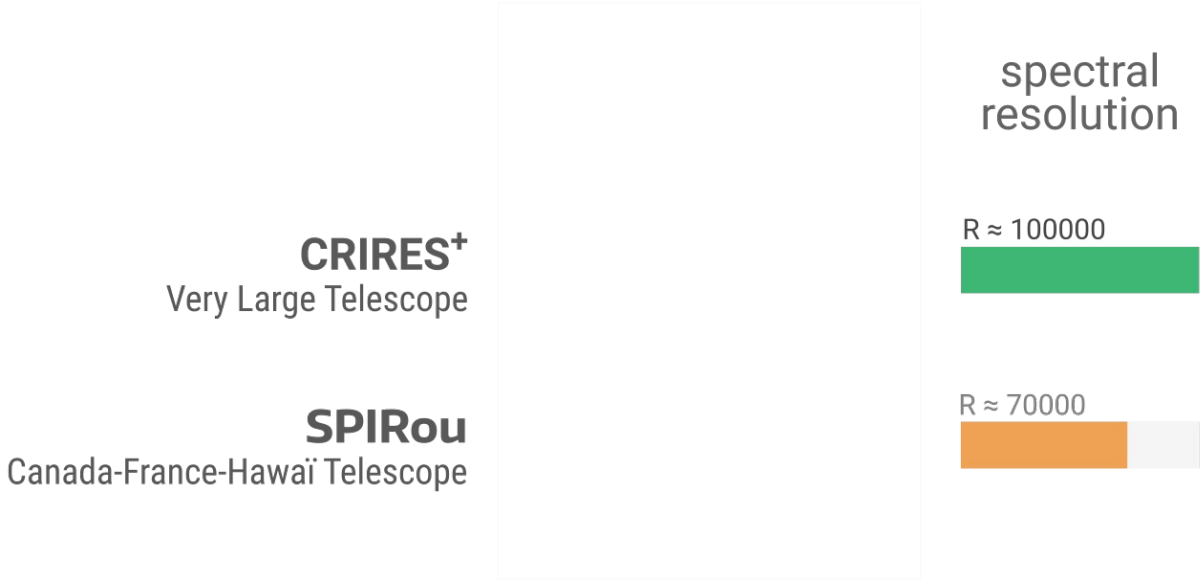

CRIRES+

CRIRES+ and SPIRou

CRIRES+ complements existing instruments such as SPIRou.



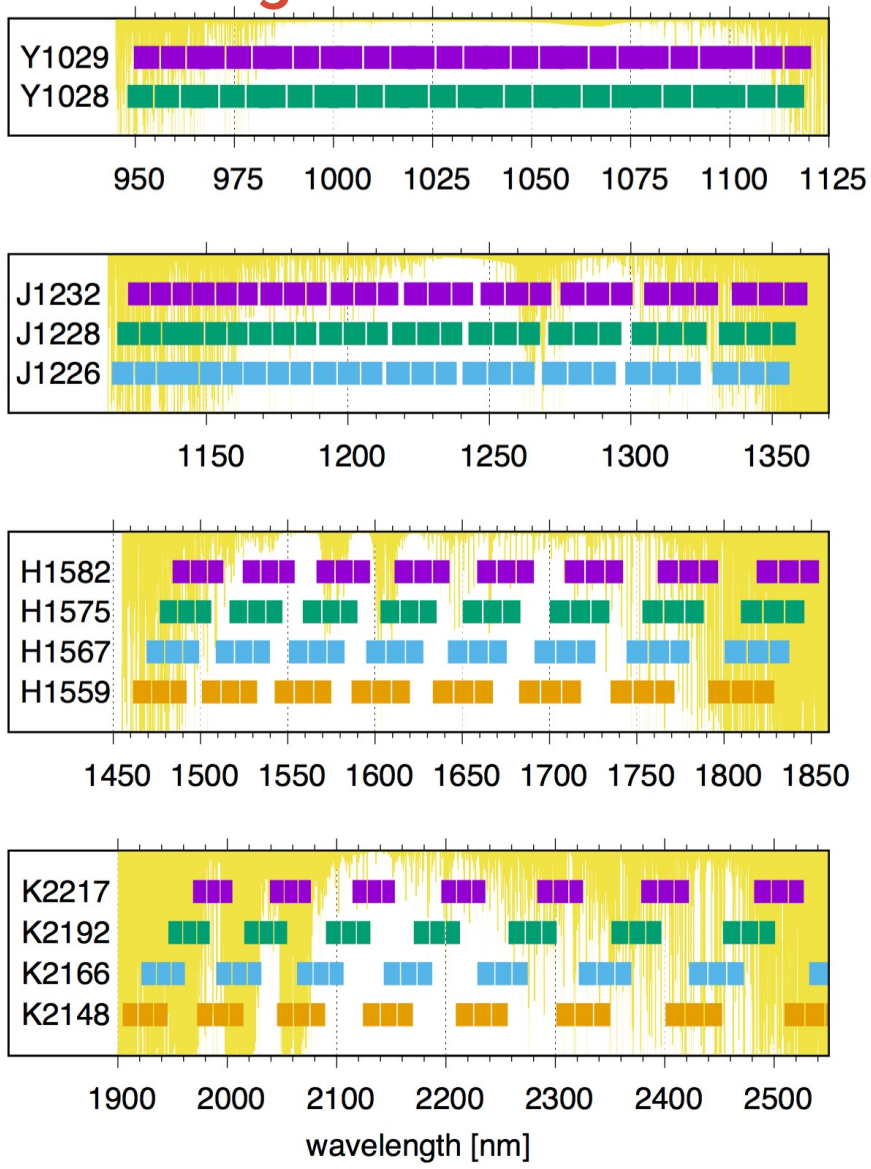
CRIRES+ and SPIRou

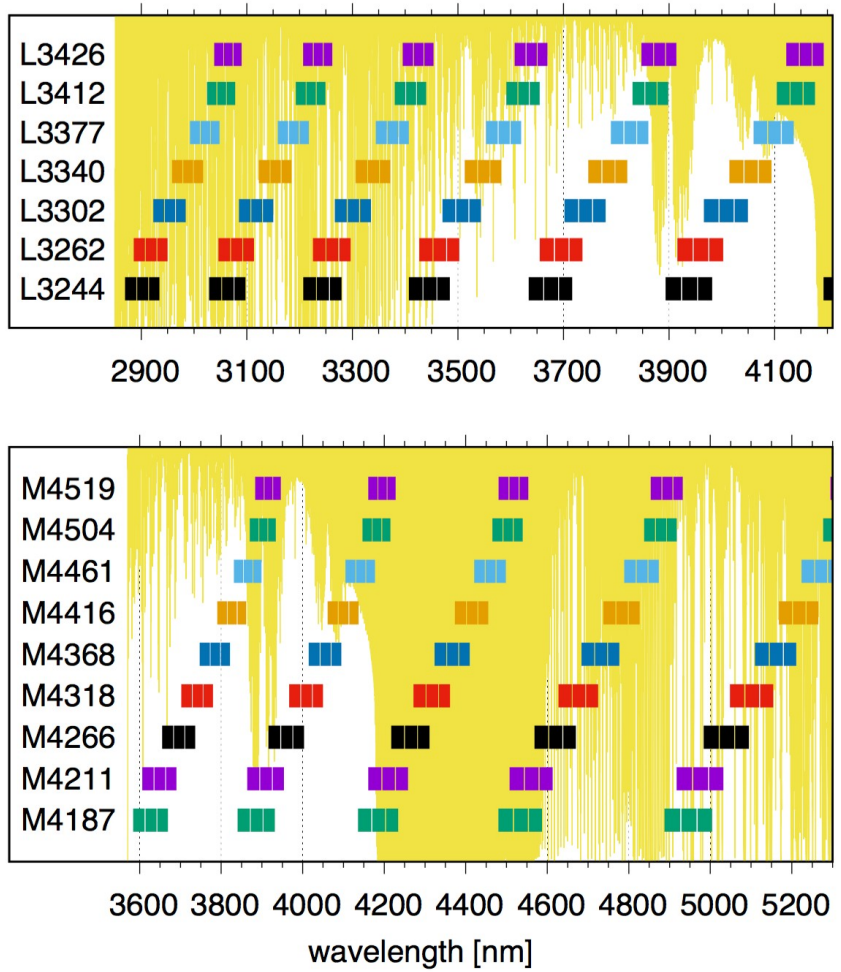


Spectral resolution can be > 100 000 (e.g 140000 measured) when AO performs well

CRIRES+ wavelength coverage

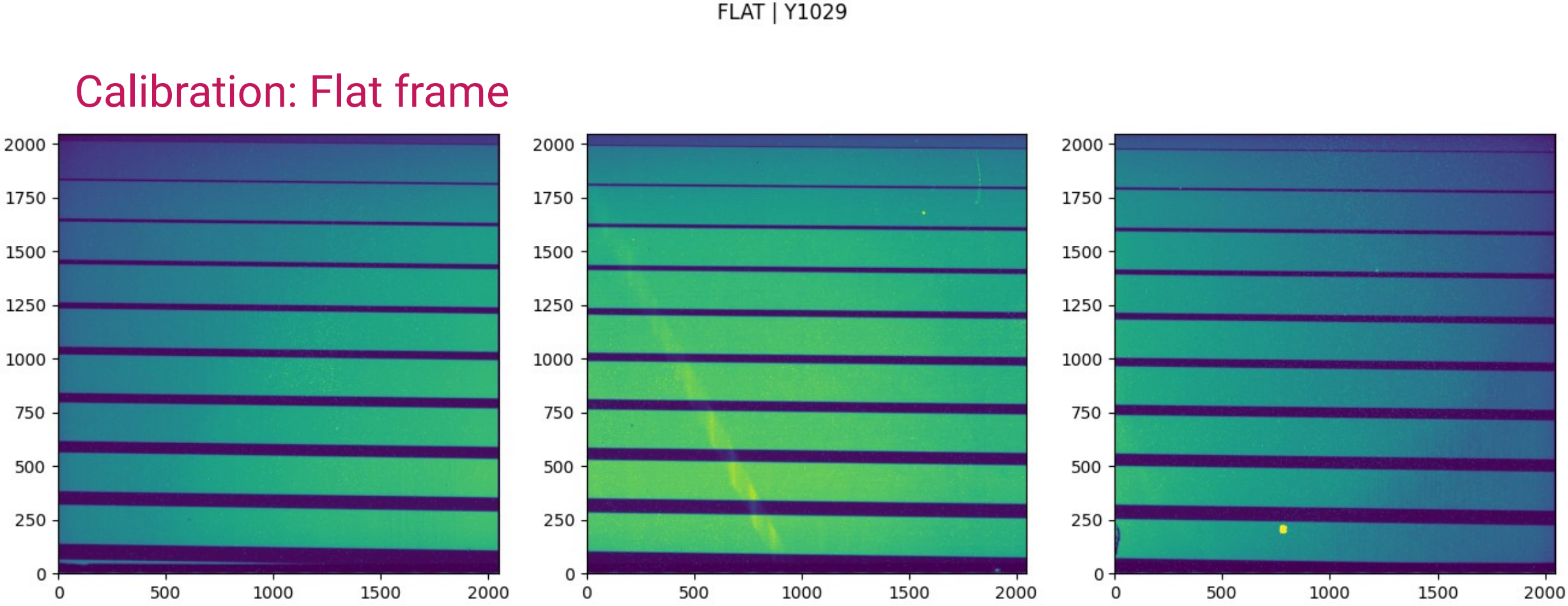
→ Wavelength coverage of all standard wavelength settings.
From the CRIRES+ user manual (Fig. 31). Hi-res figure available at this link.





Data

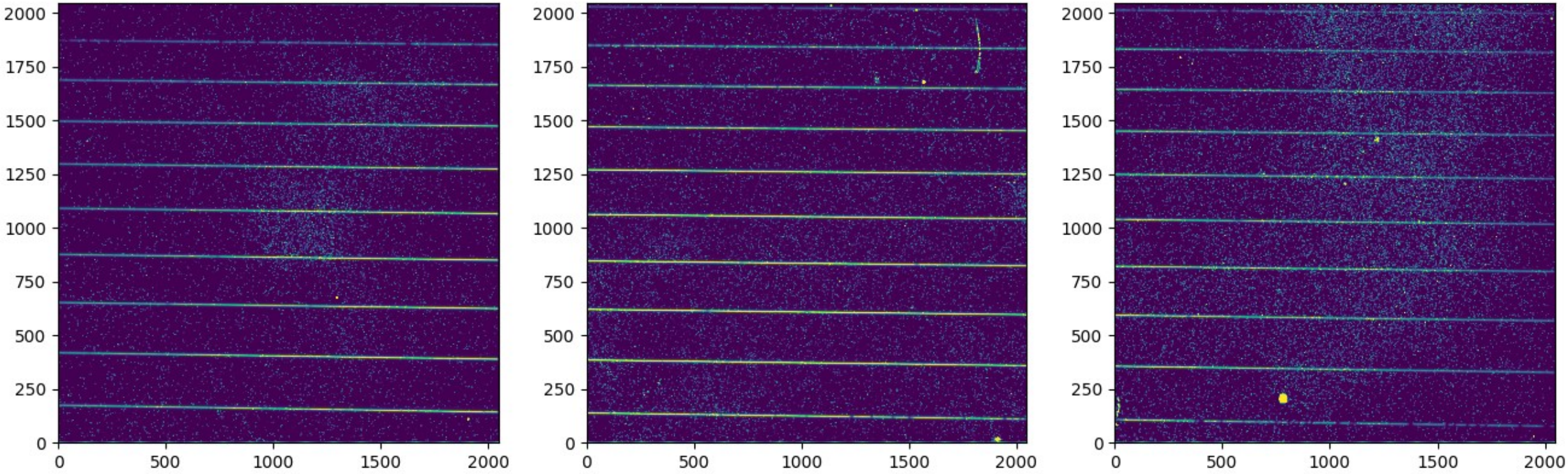
Calibration: Flat frame



Data

AU Mic | Y1029

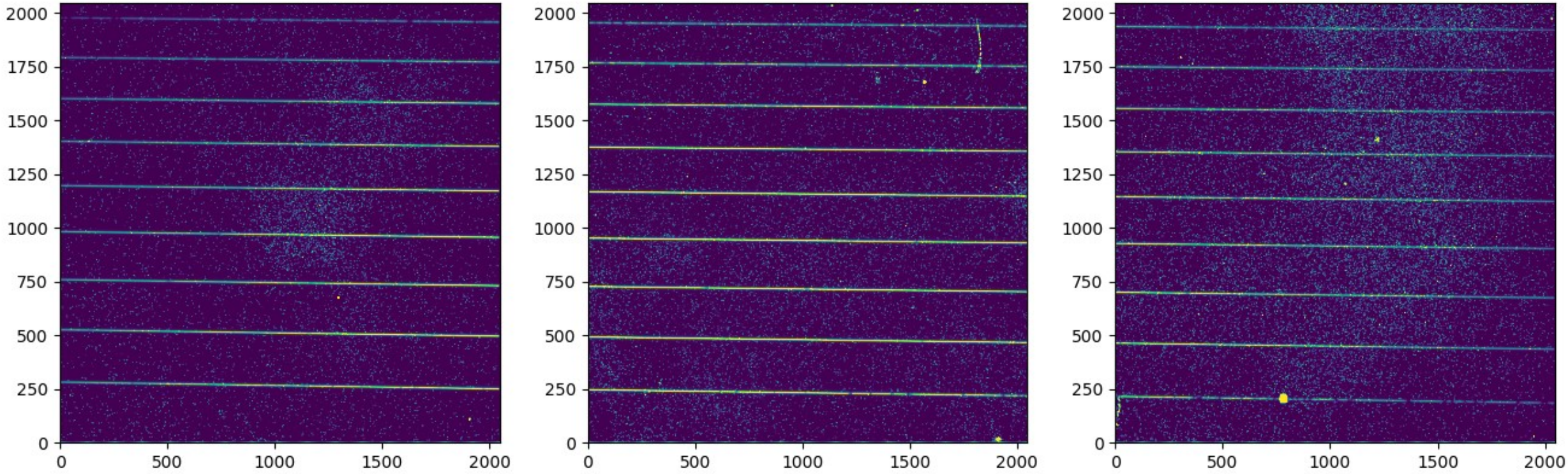
AU Mic science spectrum. Nodding position A



Data

AU Mic | Y1029

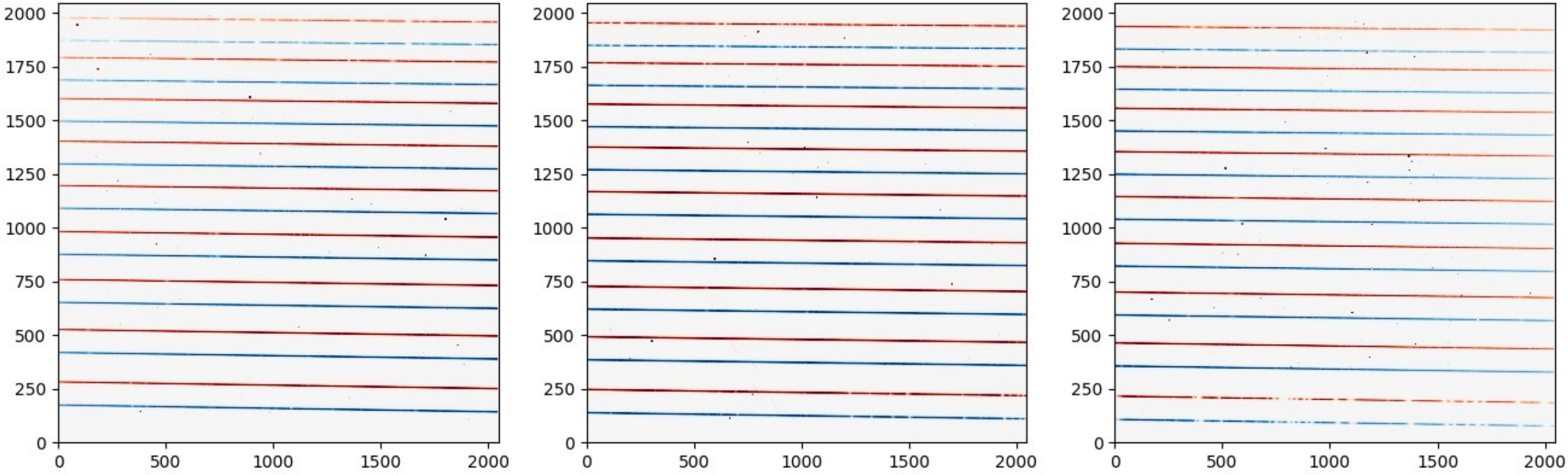
AU Mic science spectrum. Nodding position B



Data

AU Mic | Y1029

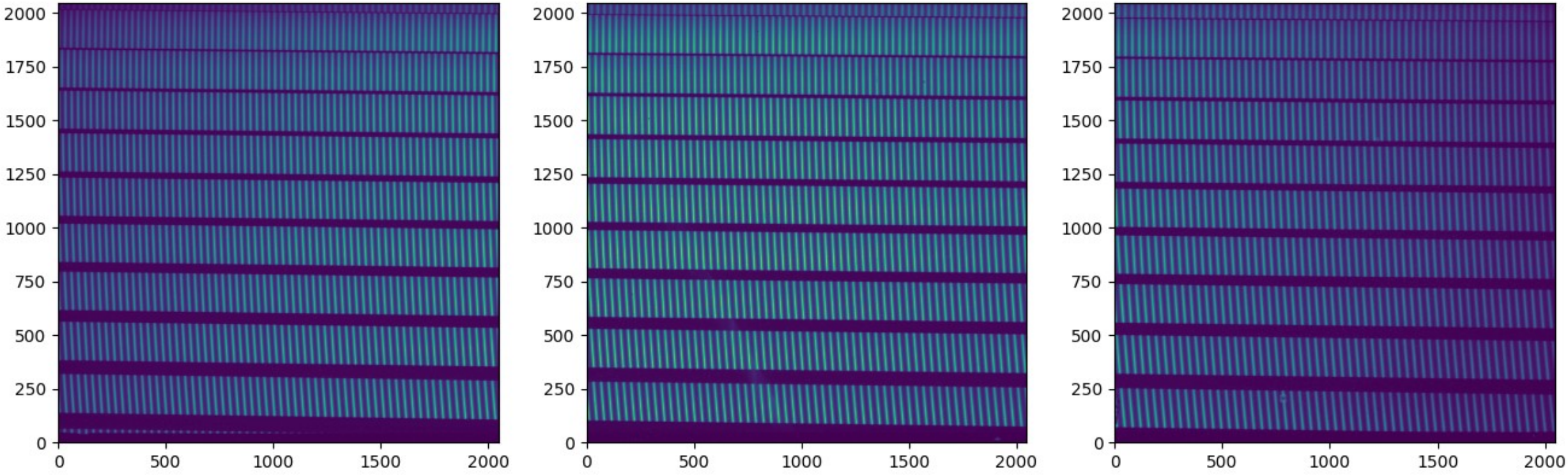
AU Mic science spectrum. Nodding position A – Nodding position B



Data

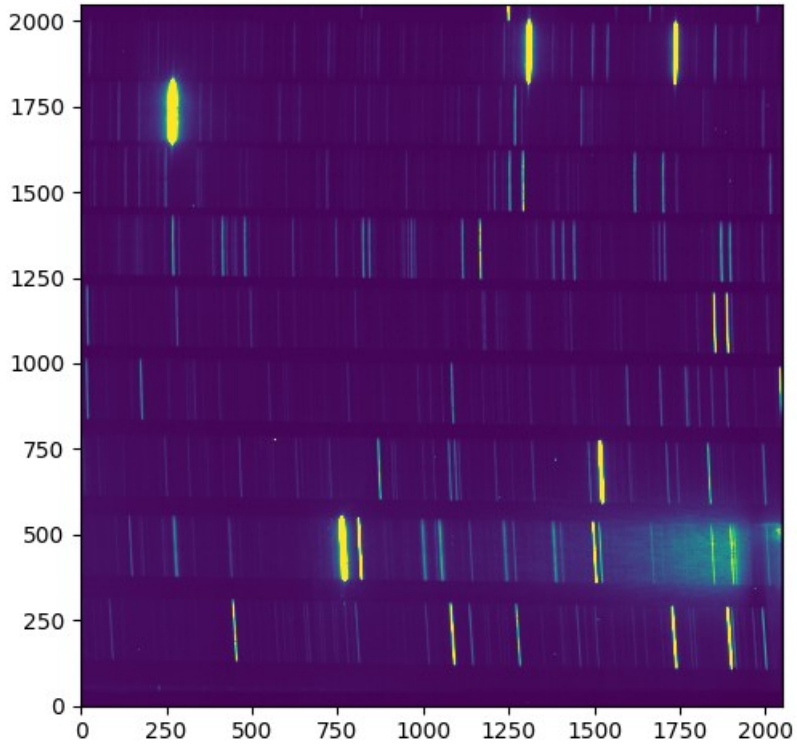
WAVE,FPET | Y1029

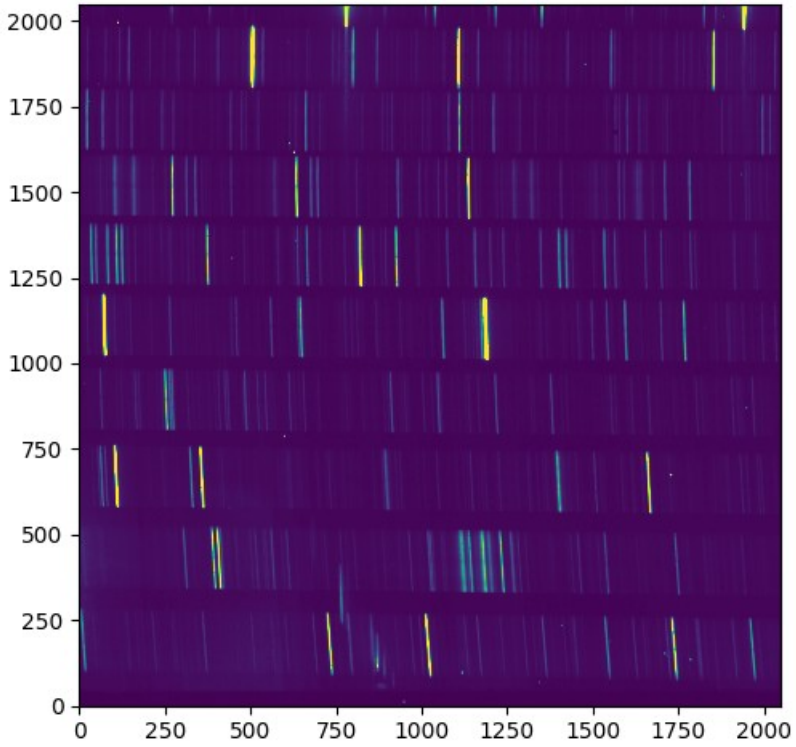
Calibration: Fabry-Perot etalon (FPET)

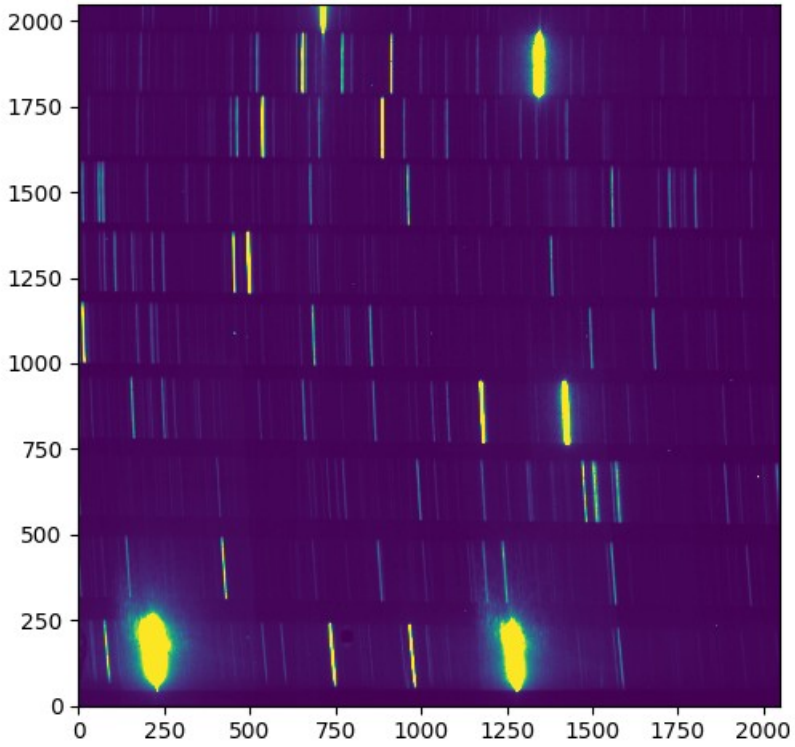


Data

Calibration: Uranium Neon lamp

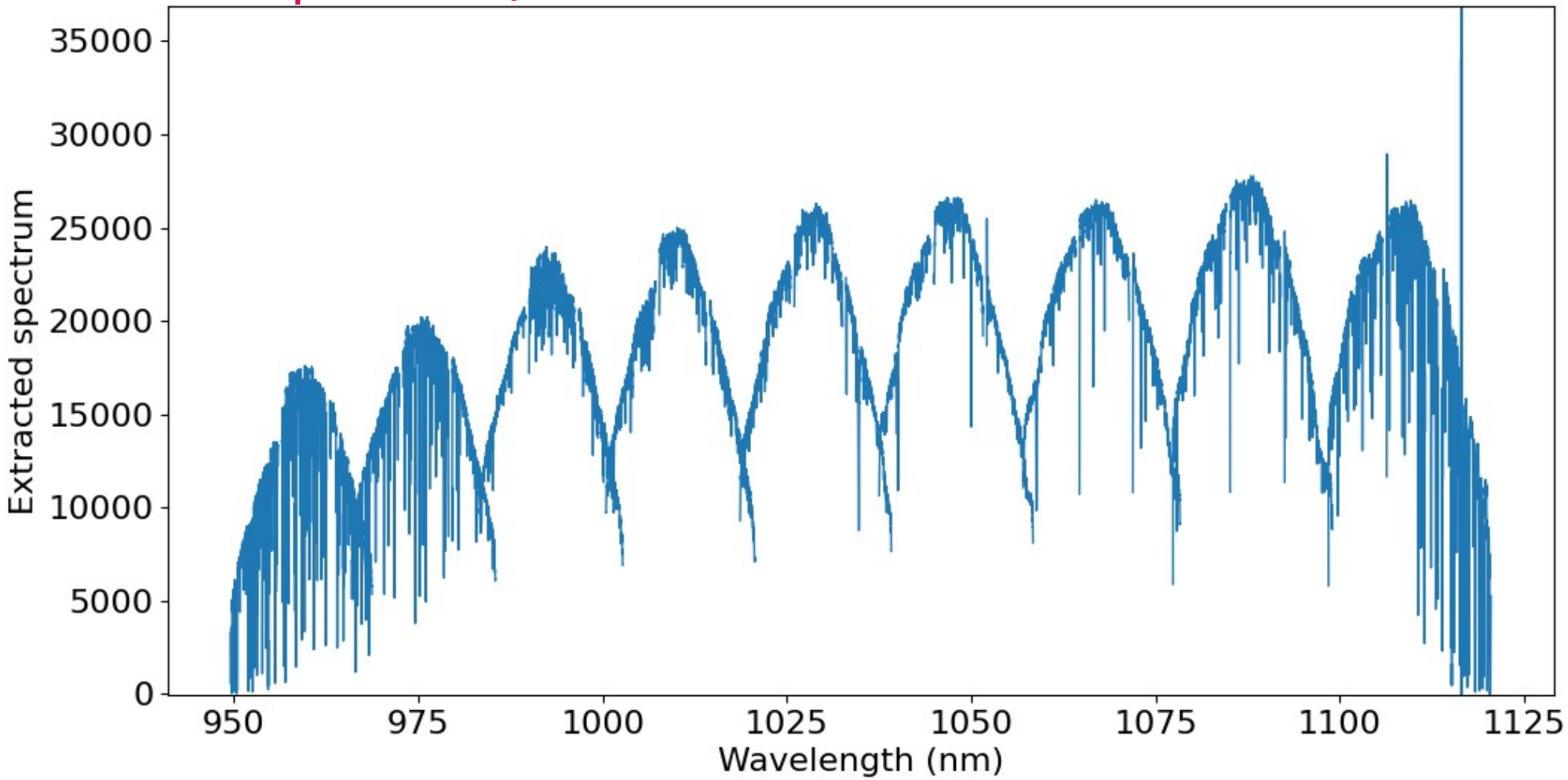






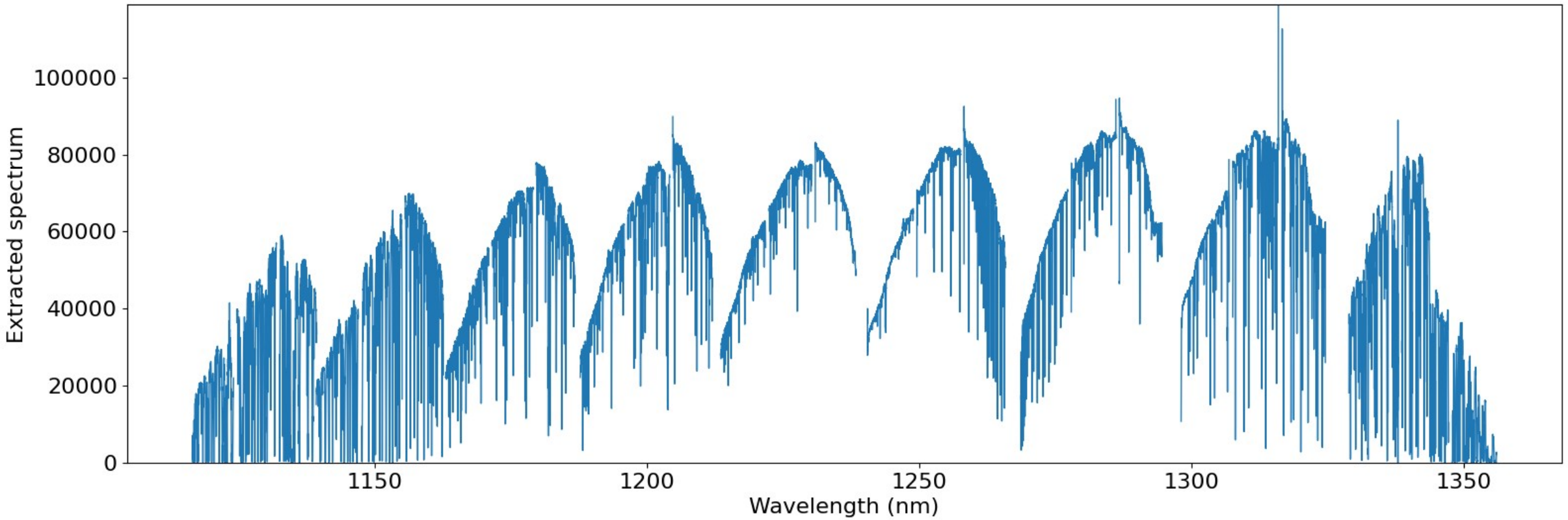
Data

Extracted spectrum | Y1029



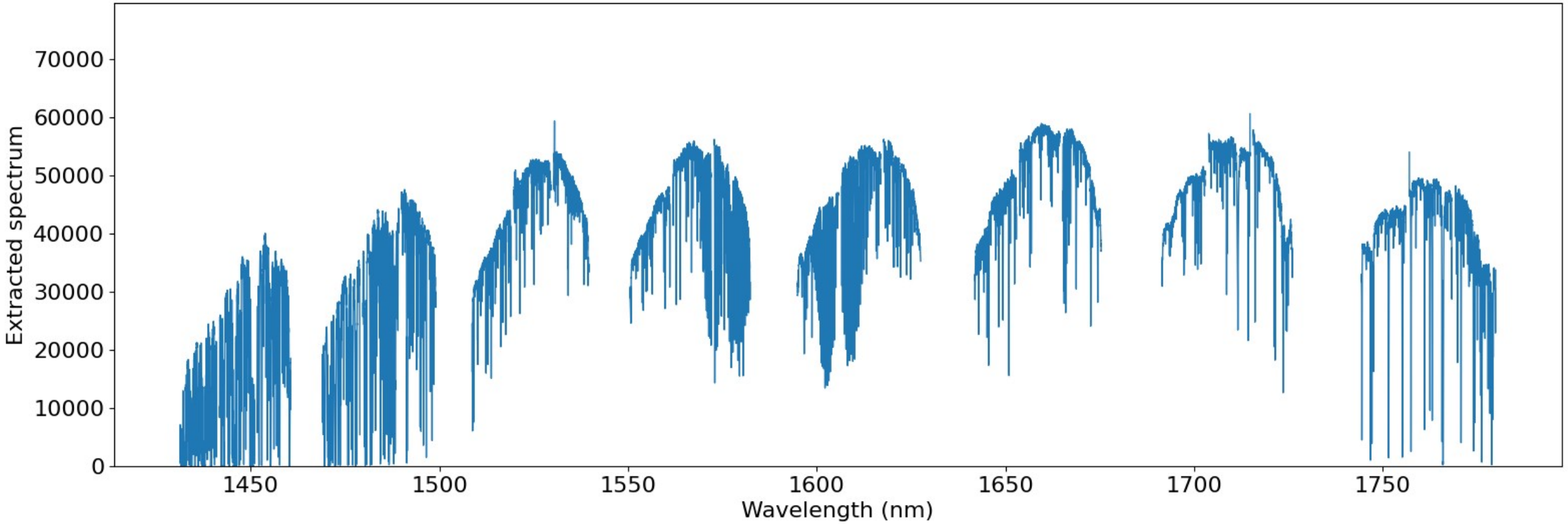
Data

Extracted spectrum | J1226



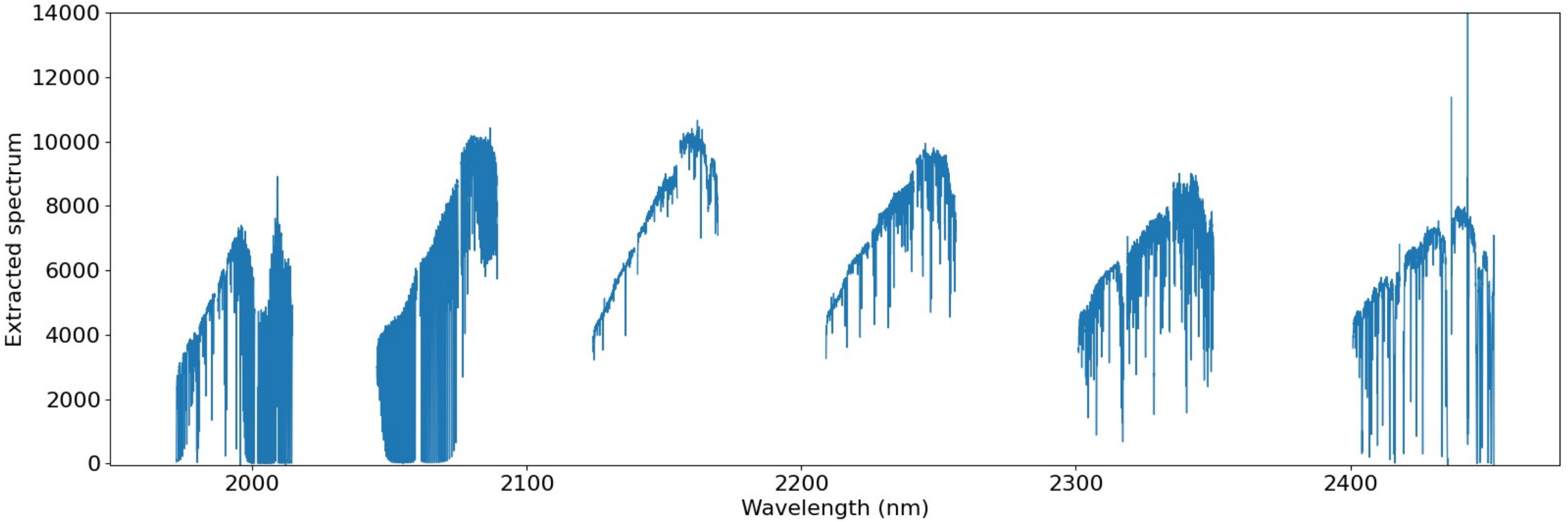
Data

Extracted spectrum I H1567



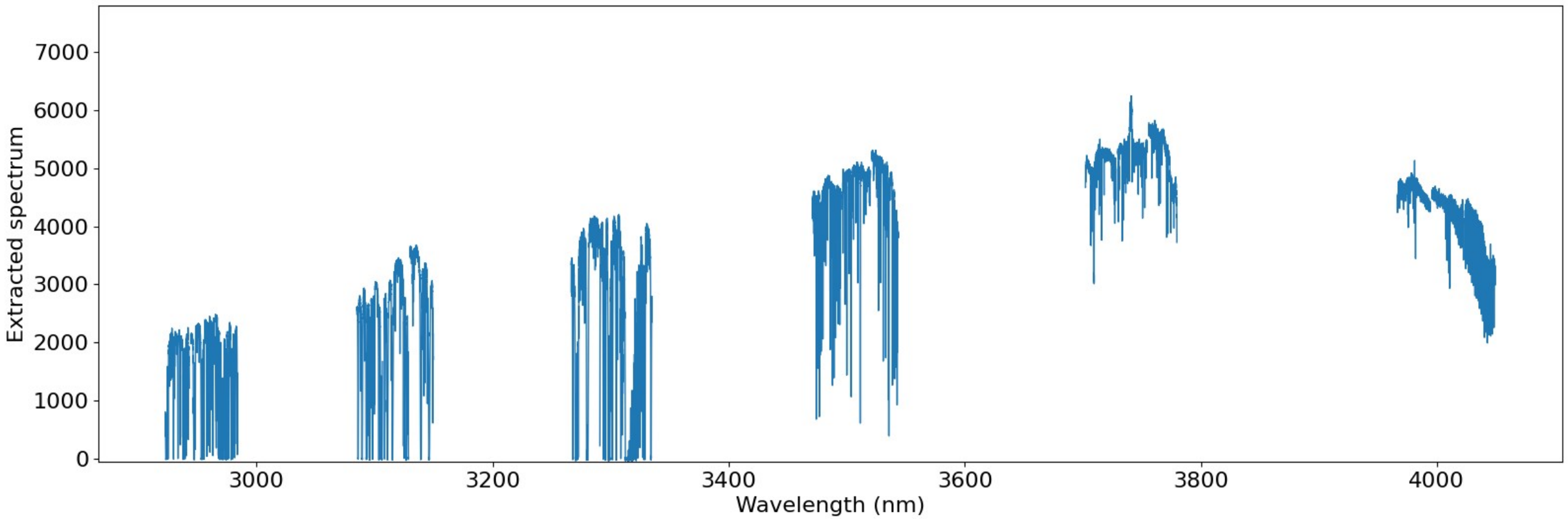
Data

Extracted spectrum | K2148



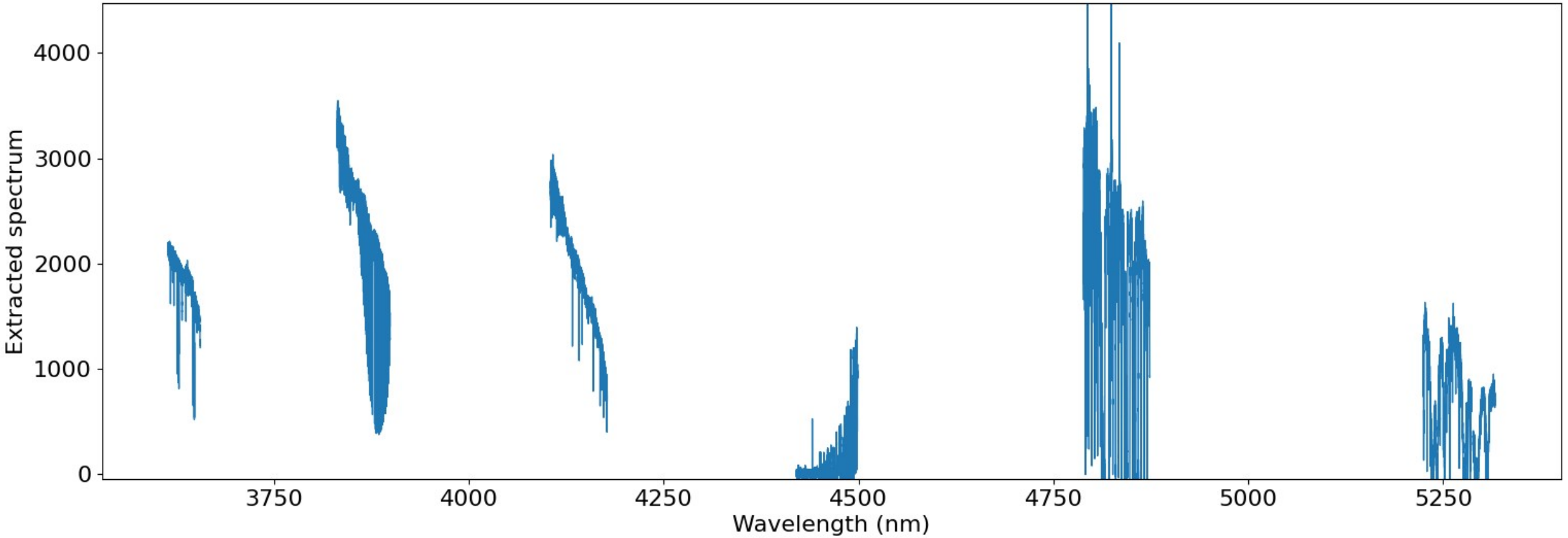
Data

Extracted spectrum | L3302



Data

Extracted spectrum | M4461



Science highlights

CRIRES+ detection of CO emissions lines and temperature inversions on the dayside of WASP-18b and WASP-76b

Yan et al. 2023; accepted by A&A; arXiv:2302.08736

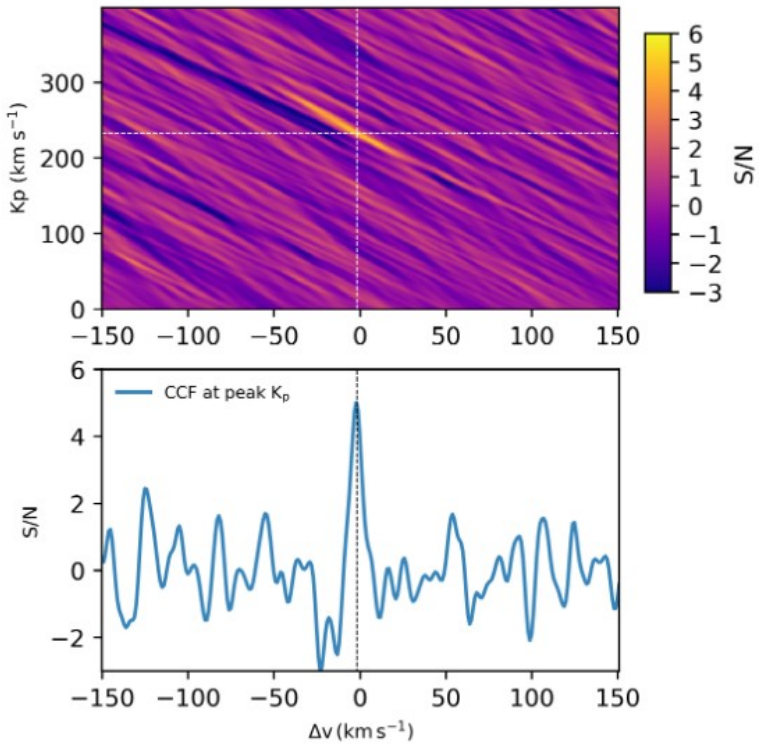


Fig. 2. K_p map (upper panel) and the CCF at maximum S/N (lower panel) for the CO signal of WASP-18b. The crossing of the dashed white lines is the location of the maximum S/N.

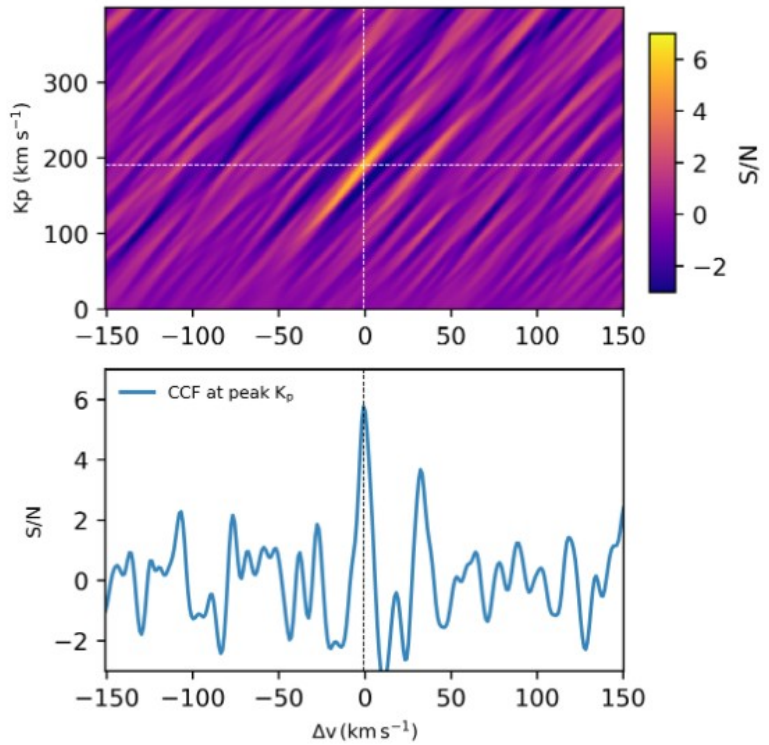


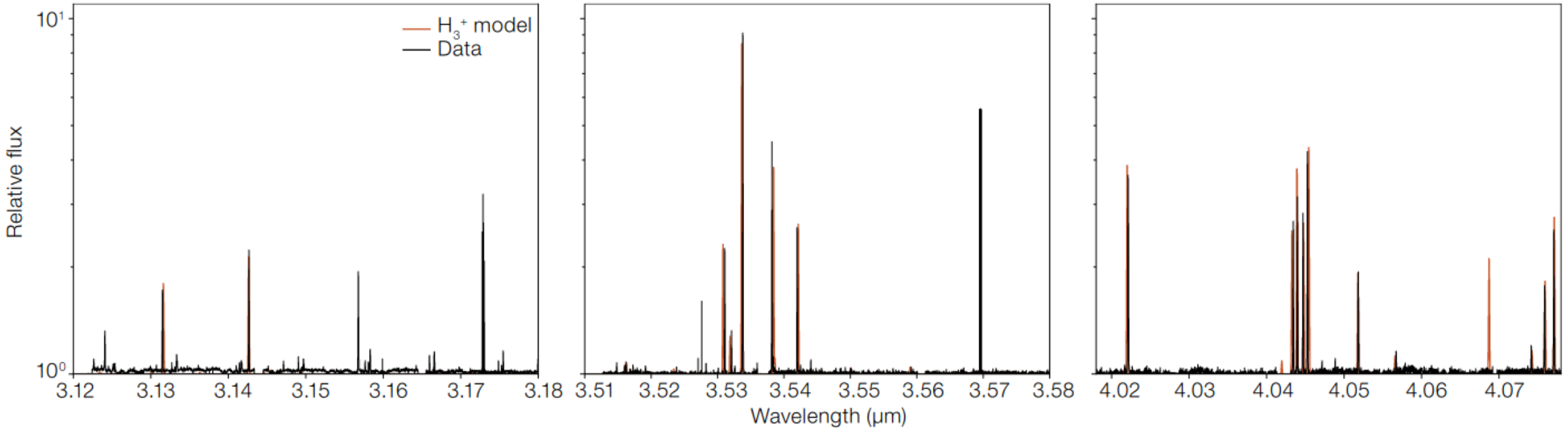
Fig. 3. Same as Fig. 2, but for the CO signal of WASP-76b.

Science highlights

Science Verification of CRIRES+

Leibundgut et al. 2022; ESO Messenger; DOI: 10.18727/0722-6691/5266

Aurora on Jupiter!



Science highlights

The Astronomical Journal, 164:79 (17pp), 2022 September
https://doi.org/10.3847/1538-3881/ac77eb

A First Look at CRIRES+: Performance Assessment and Exoplanet Spectroscopy

Måns Holmberg and Nikku Madhusudhan

The Astrophysical Journal, 932:60 (17pp), 2022 June 10
https://doi.org/10.3847/1538-4357/ac6503

Primordial Helium-3 Redux: The Helium Isotope Ratio of the Orion Nebula*

Ryan J. Cooke[1], Pasquier Noterdaeme[2,3], James W. Johnson[4], Max Pettini[5], Louise Welsh[6,7], Celine Peroux[8,9], Michael T. Murphy[10], and David H. Weinberg[4,11]

A&A 667, A106 (2022)
https://doi.org/10.1051/0004-6361/202244383

Astronomy & Astrophysics

Detecting H_2O with CRIRES+: WASP-20b*

M. C. Maimone[1,2], M. Brogi[3,4,5], A. Chiavassa[1,6], M. E. van den Ancker[2], C. F. Manara[2], J. Leconte[7], S. Gandhi[8,3,5], and W. Pluriel[9]

CRIRES+ science proposals

CRIRES+ proposals with data being public as per today

- A comprehensive study of the climate of ultra-hot Jupiters: WASP-121b as benchmark
- A reducing, hydrogen-dominated atmosphere on a warm Earth-sized exoplanet?
- CO isotopologue ratios in super-Jupiter atmospheres as a tracer of planet formation
- Cyclic C3H3+ : a search for the smallest aromatic molecule in space
- Deciphering Biosignatures of Planet Earth
- Detecting the evaporating atmosphere of a planet inside the Neptunian desert
- Detecting the secondary atmosphere of the earth-size planet GJ 1132b
- Disclosing the inner structure of HMYSOs with GRAVITY and CRIRES+
- Dynamical masses of low-mass visual benchmark M-dwarf binaries
- Exoplanet atmospheres in a new light: Probing atmospheric escape and retention with H3+
- Exoplanet atmospheres with CRIRES+
- Exploring the inner regions of the remarkable disk around the Herbig Ae star V351 Ori (PDS201)
- High-spectral resolution characterization of a directly-imaged young giant exoplanet
- Infrared vs. Optical Stellar Abundances
- Probing the atmospheric constituents of the ultra-hot super-Earth 55 Cancri e
- Searching for an atmosphere of 55 Cnc e and measuring the inclination of 55 Cnc b from L-band emission with CRIRES+
- Searching for molecular signatures and accretion emission lines in the spectrum of the forming planet PDS70b
- Stellar magnetic fields with CRIRES+: near-infrared Zeeman broadening measurements for Sun-like stars
- The transition from sub-Neptunes to super-Earths around M dwarfs - Exploring the photoevaporation valley with CRIRES+
- Unique CRIRES+ investigations of isotopic signatures in outbursting comet C/2021 A1 (Leonard).
- Unravelling spectral signatures of carbon chemistry in the atmospheres of warm directly-imaged planets
- Whence the dust in Active Galactic Nuclei

`list-crires-proposal-titles.py`

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13/22 proposals on exoplanet atmospheres

Polarimetry

Polarimetry

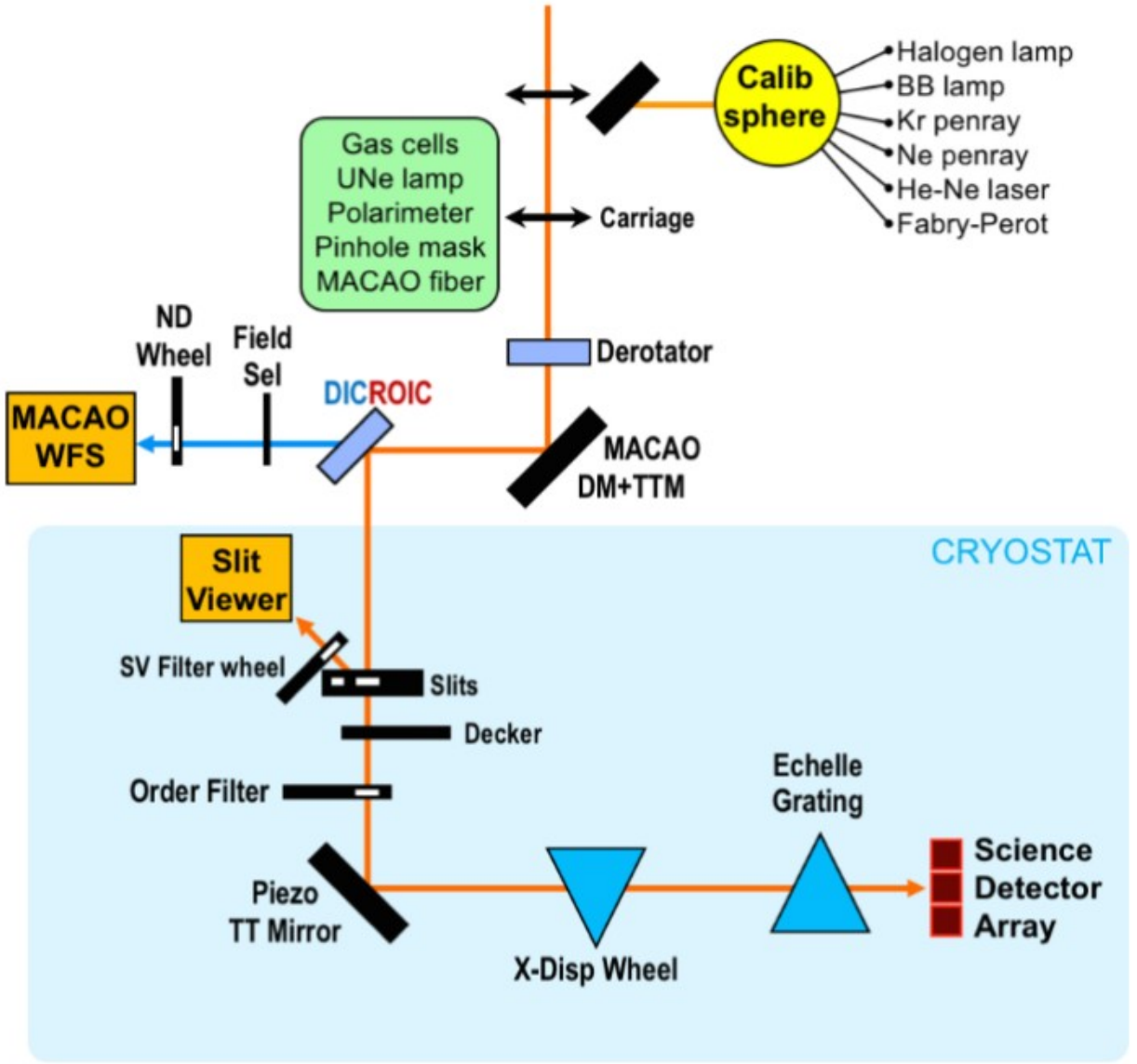
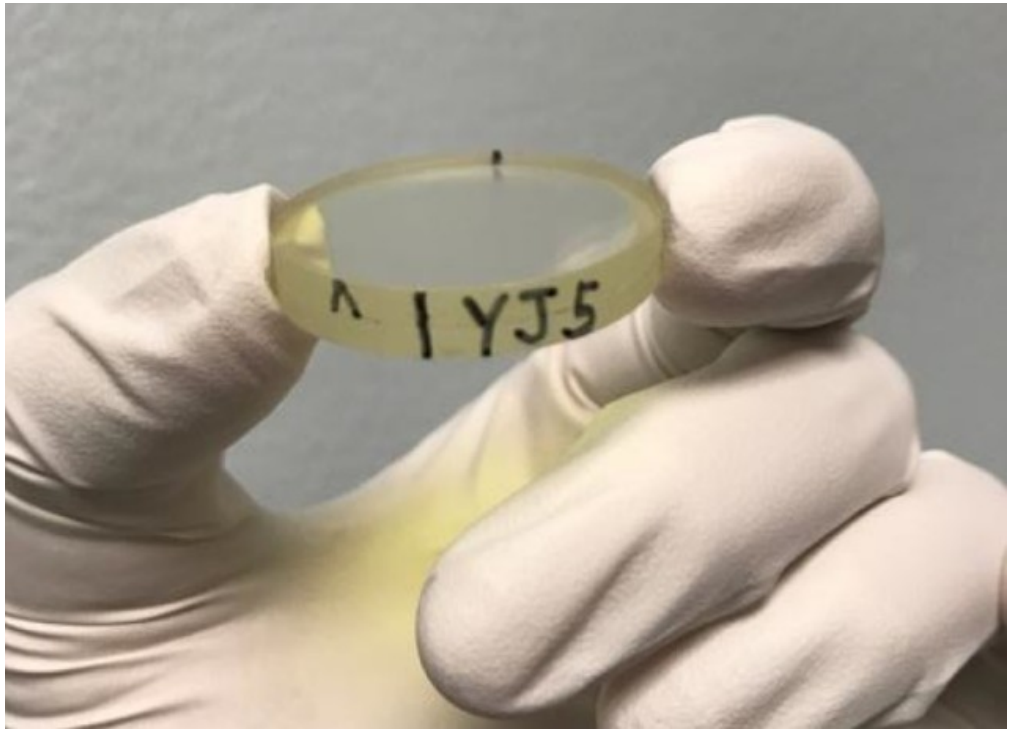


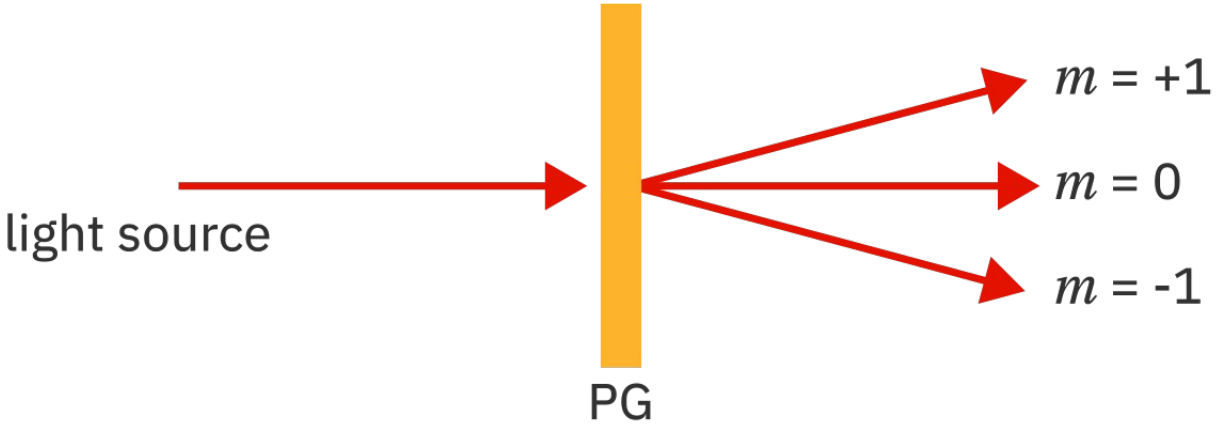
Figure 2: Light path sketch of the upgraded CRIRES.

Polarimetry

Different design than NARVAL/ESPaDOnS/SPIRou: based on pairs of polarization gratings



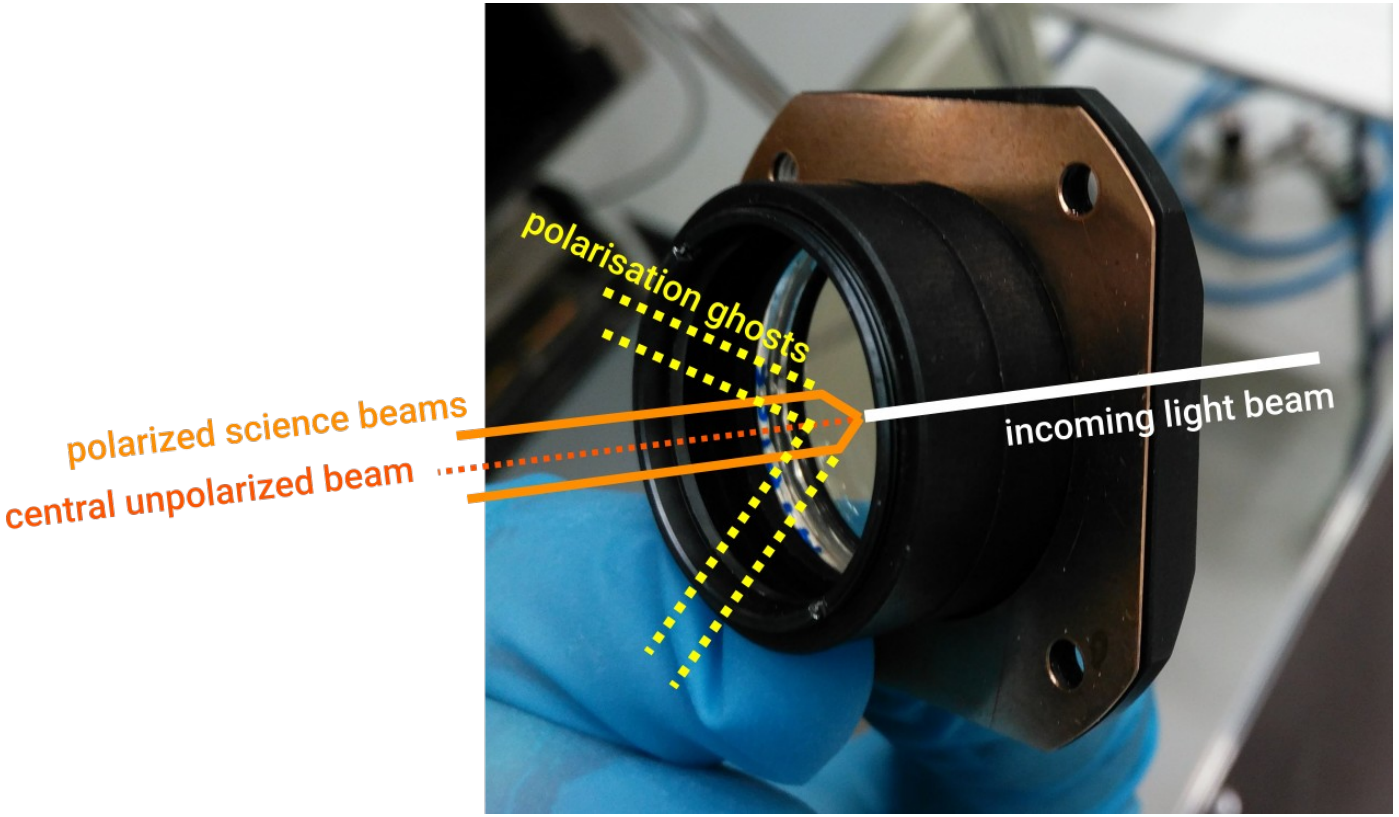
↑ A single polarisation grating for YJ bands.
From Piskunov et al. 2018



PGs are designed to:

- Let light through m=0 below cutoff wavelength
- Split light into m=±1 above cutoff wavelength

Spectropolarimetry unit



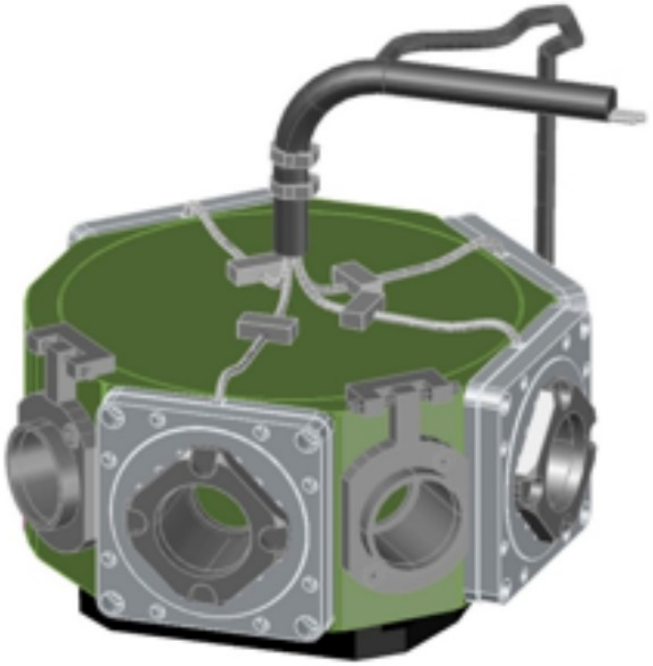
↑ Picture of a beam-splitter with schematic ray-tracing

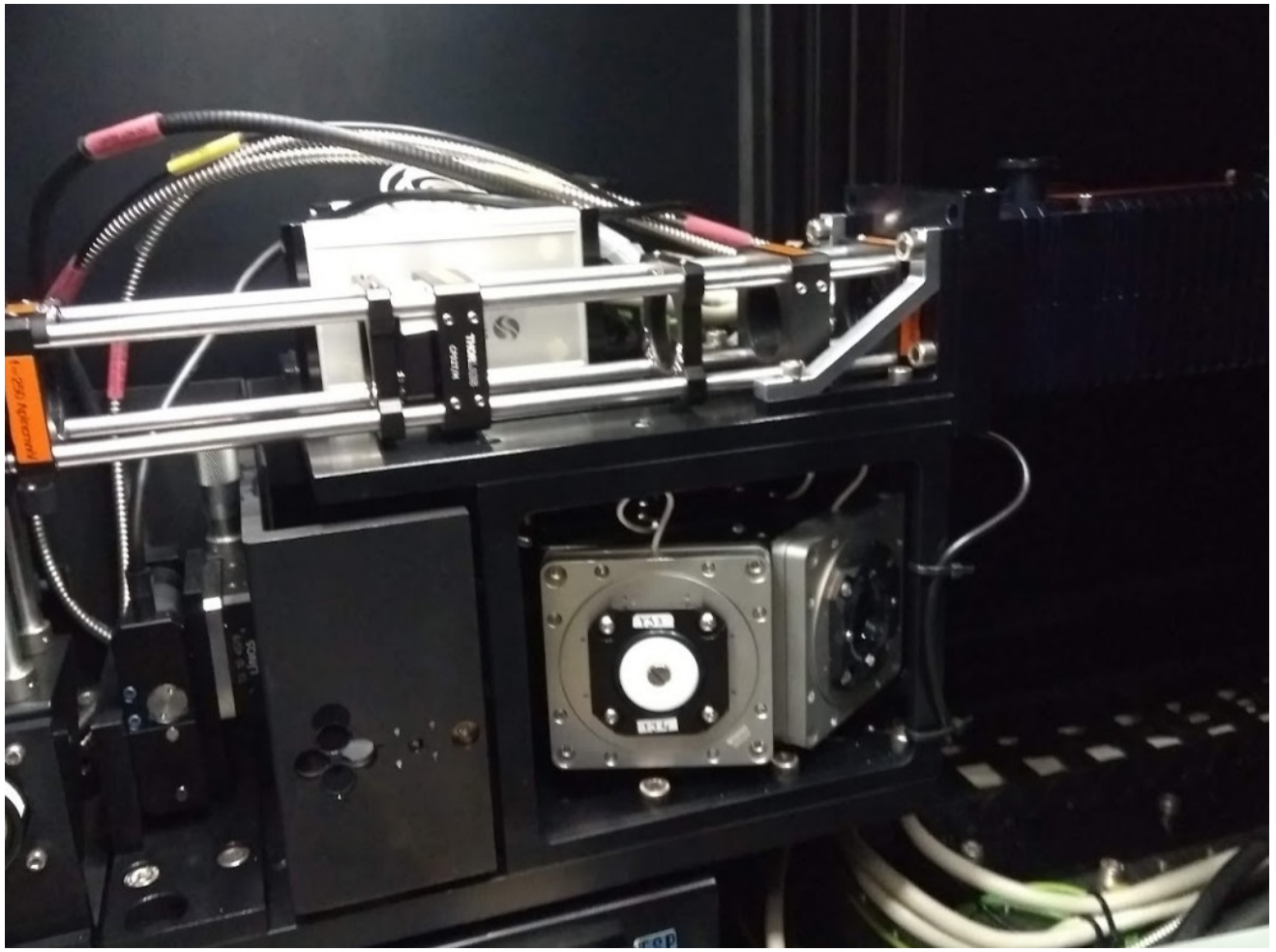
4 beam-splitters in total:

- YJ circular
- YJ linear
- HK circular
- HK linear

Beam splitter act on circular polarisation: for linear-polarisation, beam-splitters have an extra quarter wave plate.

Spectropolarimetry unit

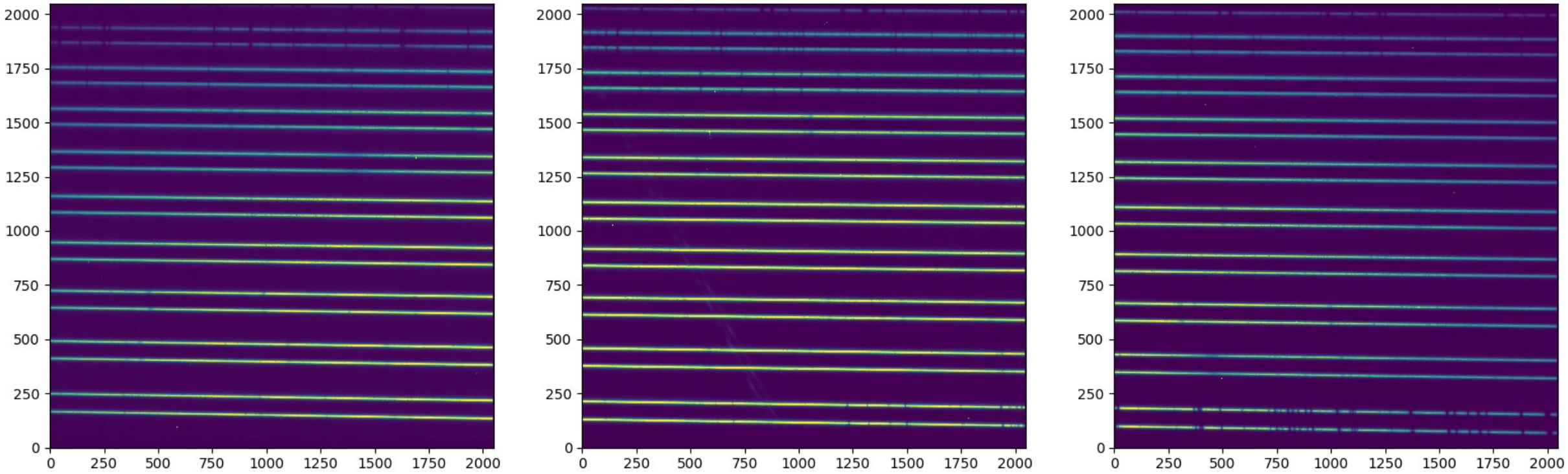




↑ Spectropolarimetry unit with the 4 beam-splitters

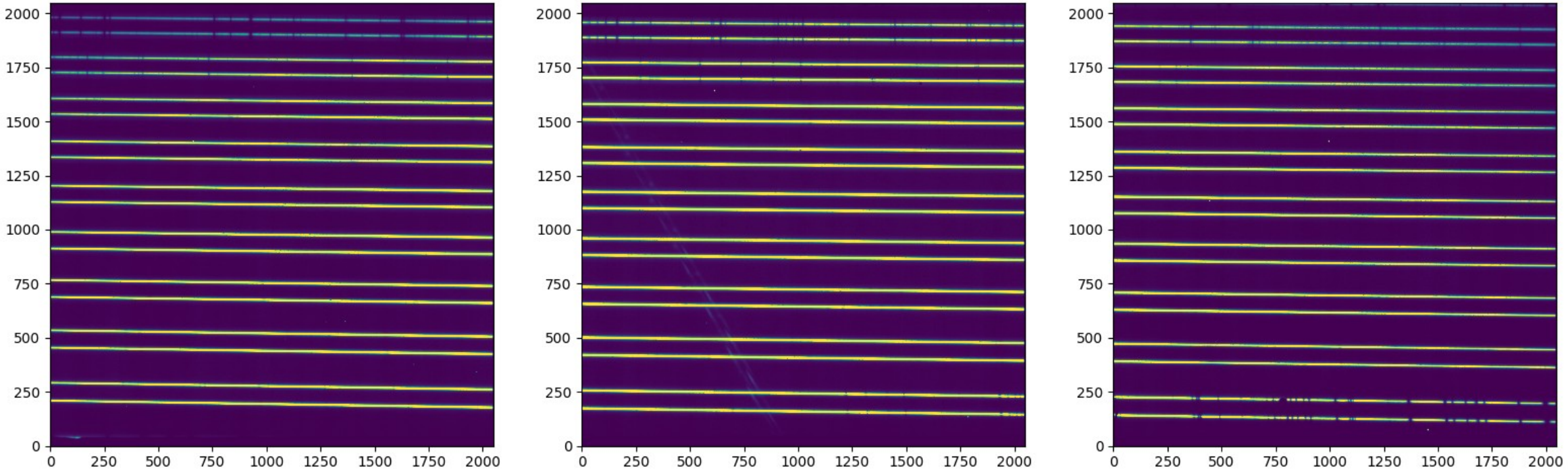
Spectropolarimetry data

Gam Equ pol spectrum. Nodding position A



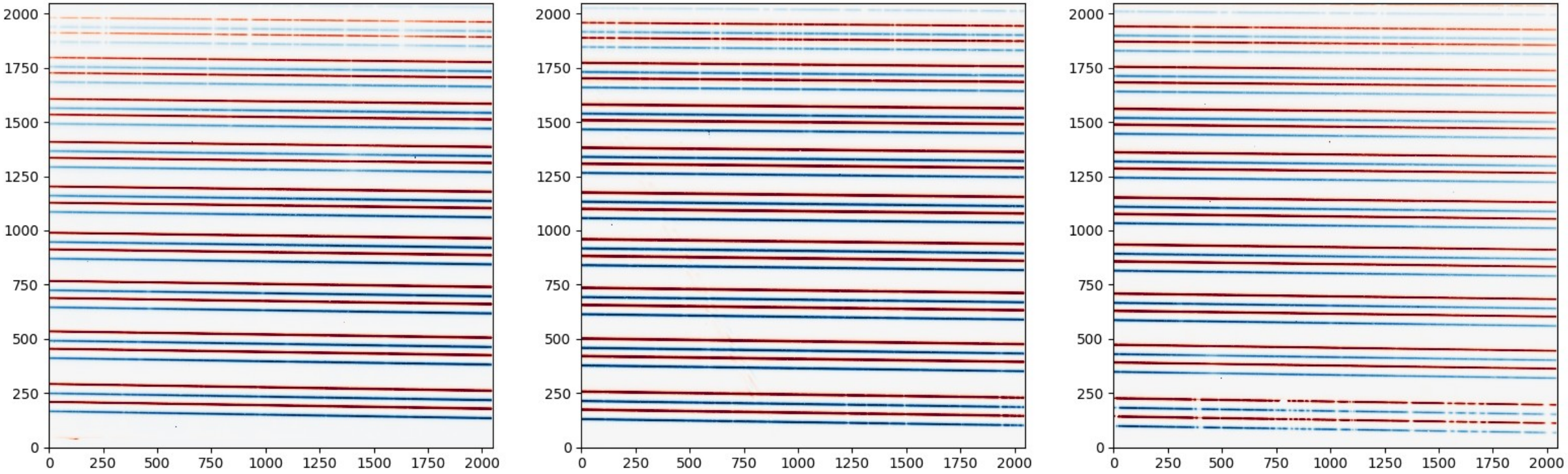
Spectropolarimetry data

Gam Equ pol spectrum. Nodding position B

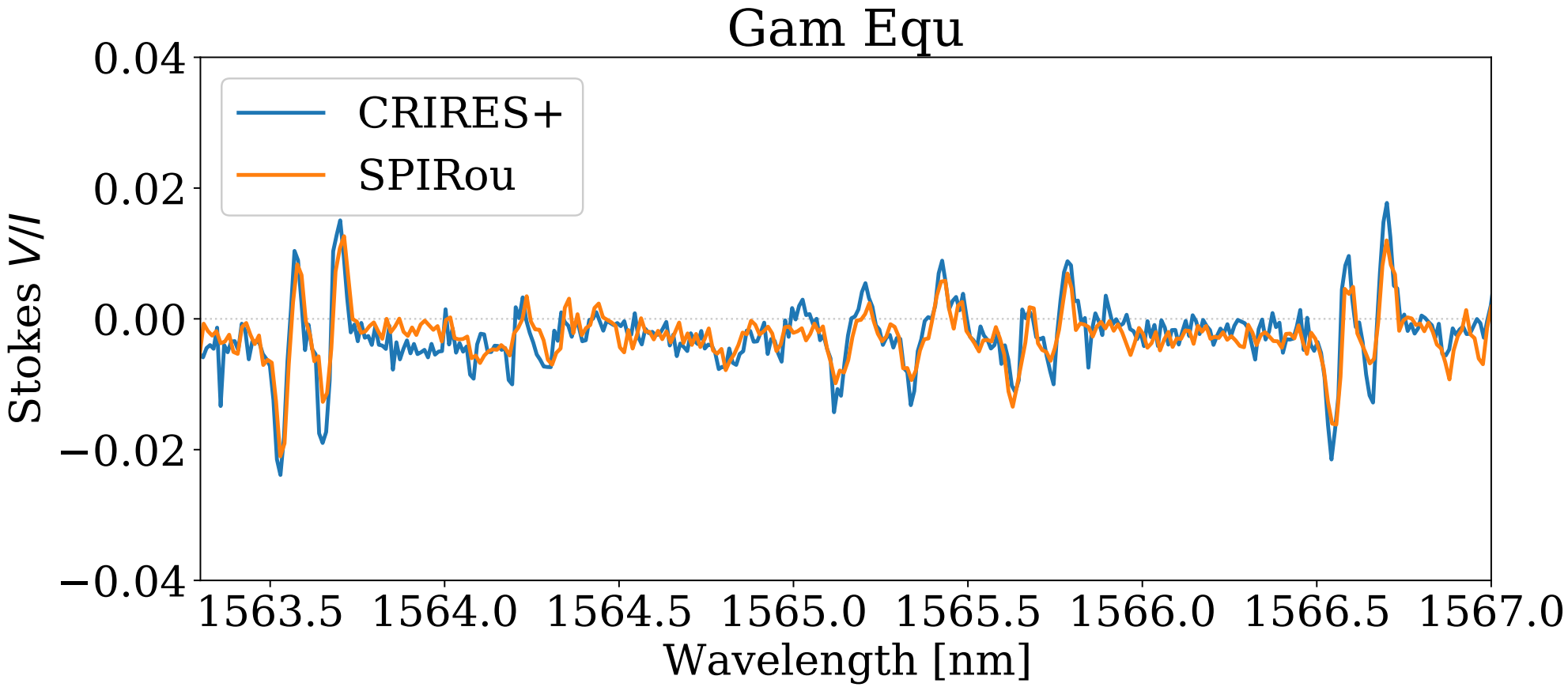


Spectropolarimetry data

Gam Equ pol spectrum. A-B



Polarimetry



Take-away message

- CRIRES+ is working well since oct 2021
- The first data is already public
- Talk/write to me if you need help planning observations, or handling data.

- Get in touch with WP Leaders if you would like to collaborate
  - Polarization/Stellar activity: **Oleg Kochukhov**
  - Planetary atmospheres : **Lisa Nortmann**
  - Radial velocities : **Evangelos Nagel**

Thanks !