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# SPINER: SPectro-INterferometry with Echelle grating at high Resolution

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## ABSTRACT

Spectro-interferometry is a powerful technique to study astrophysical objects. All modern interferometric instruments offer at least a limited spectral resolution allowing to probe geometry as the function of the wavelength. Some even offer high-enough resolutions to resolve narrow spectral features allowing to constrain physical, chemical and dynamical properties. However, due to detectors size, current instruments are either limited in term of resolution (up to 4000 for VLTI/GRAVITY to cover the full K-band) or bandwidth (20-50nm). To overcome this limitation, we started investigating the possibility of multi-order Echelle-spectro-interferometry. In such scheme, the full spectrum is divided into multiple orders dispersed perpendicularly, taking advantage of the square size of modern detectors. We are currently building a first visible prototype, allowing us to simultaneously observe the full R & I photometric bands (600-900nm) with a resolution of  $R=20000$ . We describe in this paper the instrumental concept, simulations, our first in-lab results and some driving science programs in the visible and near-infrared.

**Keywords:** Instrumentation, Interferometry, spectro-interferometry, Echelle Spectroscopy

## 1. ASTROPHYSICAL CONTEXT

High angular resolution is crucial to progress in the understanding of numerous astrophysical phenomena. Although the E-ELT will provide a suitable resolution for some, most of the stellar photospheres of near-by stars will remain unresolved by it. Long baseline interferometry is the only technique allowing one to reach the milli-arcsecond resolution needed to resolve these objects.

Prospective for visible-interferometry<sup>1</sup> has highlighted two main types of scientific programs:

- Determining stellar parameters by directly measuring their diameter
- Studying the physics of photospheres and close circumstellar environments

While the first category involves little constraints on spectral resolution and coverage of the instruments, the second highlights the interest high spectral resolution to resolve fine spectral structures. Among these programs are:

- Kinematics of photospheres: rotation, pulsations, and convection cells
- Abundance mapping for objects with low inclination and slow rotators
- Shocks and mass loss in stellar winds
- Physical conditions in the chromospheres and extended atmospheres
- Accretion in interacting binaries or for young objects
- Stellar environments: kinematics, chemical composition, physical conditions

Numerous studies have already been carried out using spectro-interferometric instruments at high spectral resolutions: CHARA/VEGA, the visible, VLTI instruments AMBER, GRAVITY and MATISSE in the infrared. However, despite the quality of these studies, they were somehow limited by a trade-off between spectral resolution and spectral bandwidth (see Fig 1 for an example).

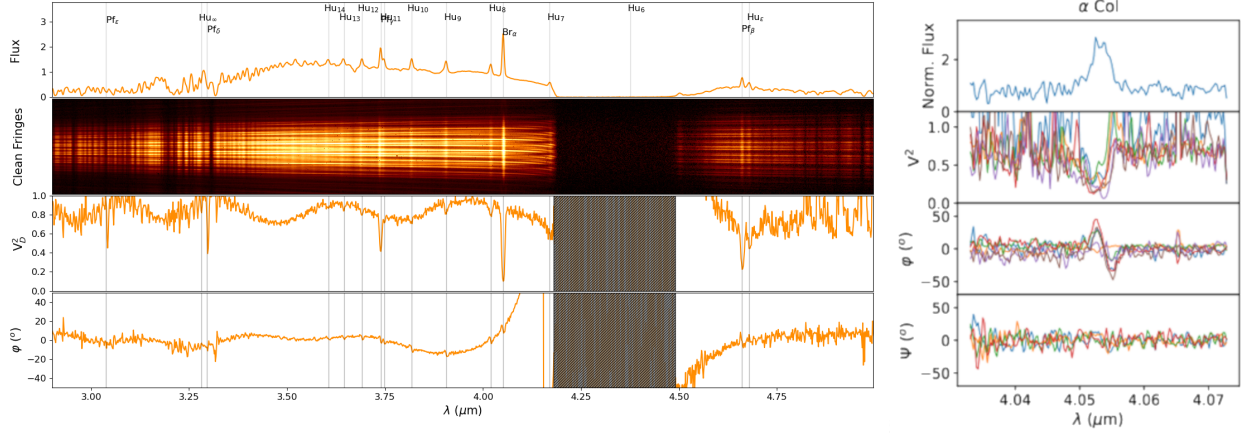


Figure 1. Comparison between VLTI/MATISSE observations of two classical Be stars at different spectral resolutions:  $\delta$  Cen (left) at  $R \sim 500$  covering the whole L-M bands ( $3\text{-}5\mu\text{m}$ ) and showing multiple emission lines, and  $\alpha$  Col (right) at  $R \sim 4000$  covering only a short band around Br $\alpha$  emission line<sup>2</sup>

## 2. INSTRUMENTAL CONTEXT

To enhance the spectral-band of spectro-interferometric instruments at very high spectral resolution we aim at testing the combination of interferometry with dispersion of the Echelle-spectroscopy type which would make it possible to take the best advantage of the large size and square format of current detectors by dispersing the spectrum in two dimensions. This type of dispersion has proven useful in spectroscopy and spectro-polarimetry (UVES, X-Shooter, NARVAL), but its combination with interferometry has never been tested.

Beyond lab tests, a spectro-interferometric-echelle instrument would need the following conditions that are either already available at VLTI and CHARA or in development:

- low noise EMCCD
- Efficient adaptive optics systems on the telescopes
- Spatial filtering through optical-fibers
- efficient fringe-tracker allowing to “freeze” fringes for many seconds

## 3. DESIGNING THE SPINER TEST-BENCH

SPINER is designed as an evolving interferometric test bench to study the different problems that Echelle spectro-interferometry can pose in terms of optical and mechanical design, transmission, detector, and data analysis. It has been designed to be easily installable as a prototype on the CHARA/SPICA<sup>3</sup> 6 telescopes visible instrument and uses the same pupils' configuration, but the concept could also prove useful for a future near-infrared (especially in the I and J bands) or visible instrument at VLTI..<sup>4</sup>

The spectral-resolution will be  $R \sim 20000$ , which is the minimum for most of the science-cases. The spectrum will cover the full 600-900nm domain. Initial plan was to go down to 450nm, but the spectral-window was limited by the size of the detector (2048x2048). Moreover, interferometry below 600nm has proven very hard due to atmospheric turbulence and the possibility of decent fringe tracking at such low wavelength is hazardous.

SPINER echelle-spectrograph consists of two dispersers :

- an Echelle-grating : 75 traits/mm, with a  $17.45^\circ$  blaze used at orders 9 to 12 (see Fig 2 left)
- a  $60^\circ$  prism for transverse dispersion with  $V_d = 25.16$   $n_d = 1.805$

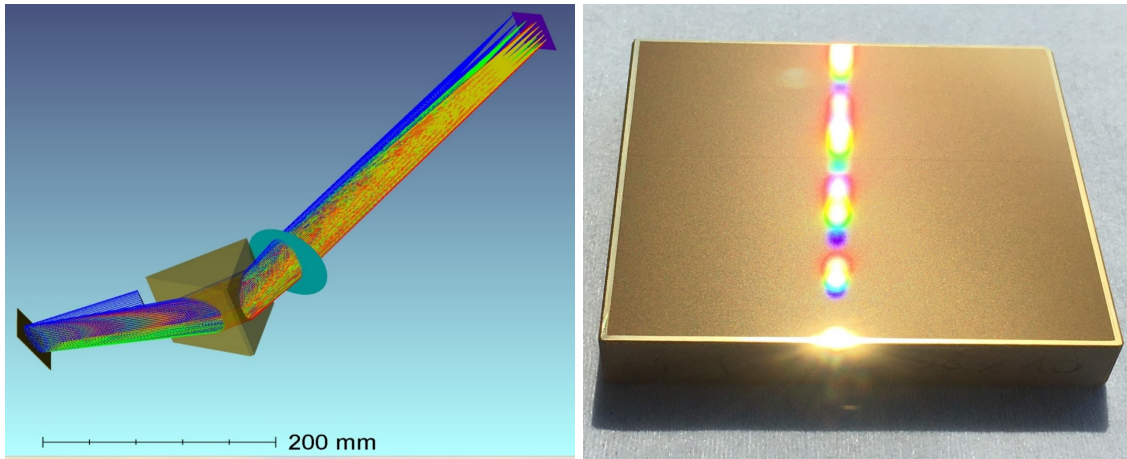


Figure 2. Left: Optical design of the SPINER spectrograph. Right: photo of SPINER echelle grating.

The 600-900nm spectrum is divided on 4 orders, dispersed a 2048x2048 detector. Note that part of the 8th and 13th orders are also visible on the detector extending the possible spectral-band to 550-1050nm. The smallest fringes is sampled on 3 pixels and the spectral sampling is also 3 pixels. Fig 3 shows a simulation of SPINER fringes pattern with non-zeros optical path difference on the 6 beams.

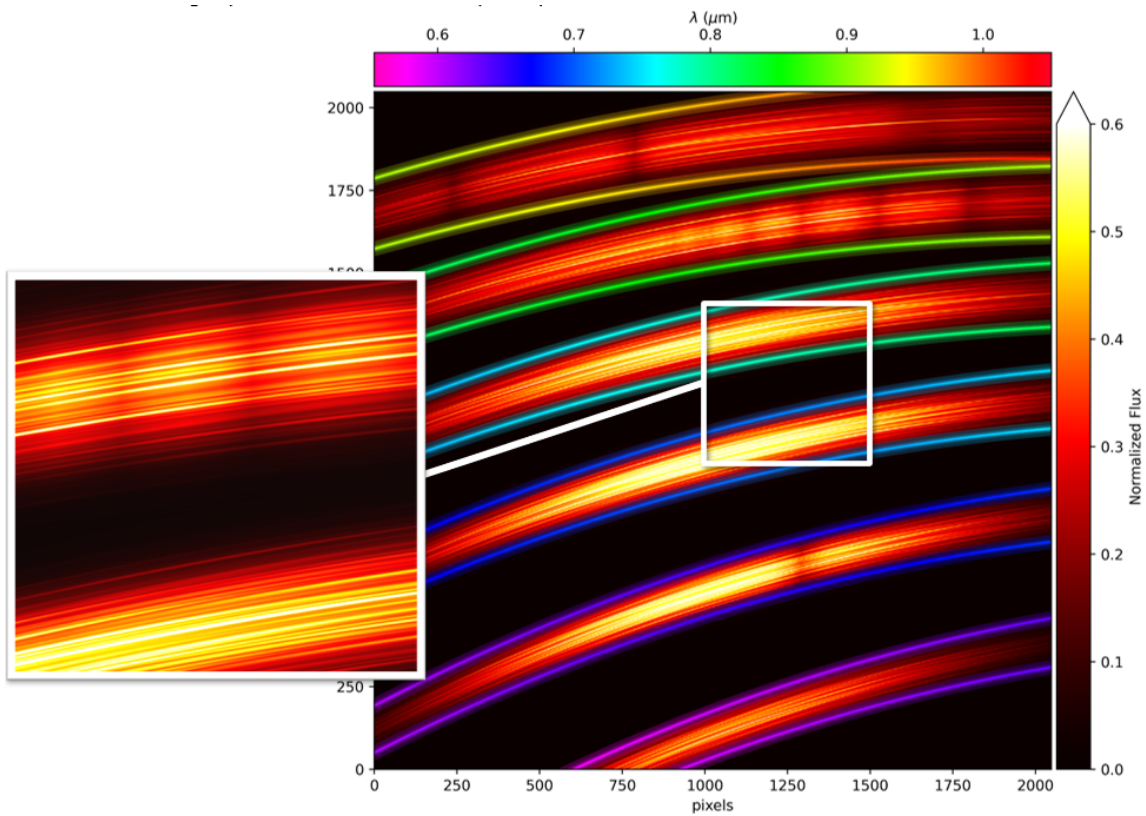


Figure 3. Simulation of SPINER fringes for a 12000K star on the 2048x2048 pixels camera. Wavelength is indicated by the colour of the glowing lines framing the fringe pattern

## 4. CONCLUSION & PERSPECTIVES

The SPINER project aims at testing the possibility of Echelle-spectro-interferometry for a future generation of instrument at CHARA and VLTI focusing mainly on the visible domain where very high spectral-resolution is needed.

The integration of the SPINER test-bench will start in September 2024 in Nice and should be finished before the end of the year. The in-lab characterization of the instrument and its fringe pattern will go on in the first half of 2025, as well as a development of a thorough simulator with inputs for the test-bench, the CHARA infrastructure, the SPICA instrument (AO, fringe-tracker, transmission), and from potential science detectors for future on-sky tests.

The perspective of doing spectro-interferometry with high resolution and large bandwidth will open up new possibilities, like lines series analyses, line binning, etc. An extension to the Y and J bands is straightforward and would open up the possibility to make high-spectral resolution science with full coverage at the VLTI.

## ACKNOWLEDGMENTS

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