Preliminary study of a multiplexing design for an intensity interferometry instrument at optical wavelength

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Abstract

Intensity interferometry was abandoned in favour of amplitude interferometry in the 1980s because of its lack of sensitivity. However, improvements in detection systems combined with a multiplication of spectral channels could lead to a revival of the method. Implementing the multiplicity of channels, taking care of the synchronisation between telescopes and reducing temporal dispersion are all challenges that need to be met for the method to work properly. We therefore present the preliminary design of such an instrument centered on 420 *nm* with 16 channels per telescope. With the large telescopes in Hawaii separated by maximum 800 *m*, we aim to measure the bunching peak of Sirius B with a SNR~5 as a proof of concept.

Multiplexing Instrument

16 Detectors

LINPix detectors (Photonscore) are ultra-fast single-photon detectors. Their jitter reach **35 *ps* FWHM** for 1 *Mcps*. And their dead time is about 2 *ns*. They reach **33 % of quantum efficiency** at 420 *nm* for a large active surface diameter about 8 *mm*.

Grating

The grating (3600 *gr/mm*) has been chosen to be **extremely dispersive (5.5 *mrad/nm*)** and with 80% transmission at 420 *nm*. This volume phase holographic (VPH) grating induces an important temporal dispersion that has to be compensed.

Periscope

The double mirror before the grating aims at controlling the angle on the grating. To get the best performance of our grating we need **to arrive with an angle of 49.1°.**
There is also discussion about replacing the periscope by an inclined optical bench, to avoid losing efficiency.

Blue Fiber

We choose a special graded-index multimode fibers with low attenuation and dispersion in the blue (**Dispersion< 1 ps/m**, attenuation : 75-90 dB/km @420, **NA : 0.12**). **The fiber core is 400 *µm*** and their length is 5 & 10 *m*.

Constraints on the optical system

1) The numerical aperture of the fiber should be **smaller** compared to the one from f1.

2) The image of the fiber must be small relative to the slices thickness of the slicer. Otherwise, a **non-square spectrum and overlaps** occur, as in Figure 4, which reduces the SNR.

3) The numerical aperture on the slicer must be small enough to allow **clean separation of the beam without overlap.**

4) The dispersion of the grating and f2 should be sufficiently large **to have a sufficient dispersion on the slicer.**

5) The temporal dispersion needs to be small.

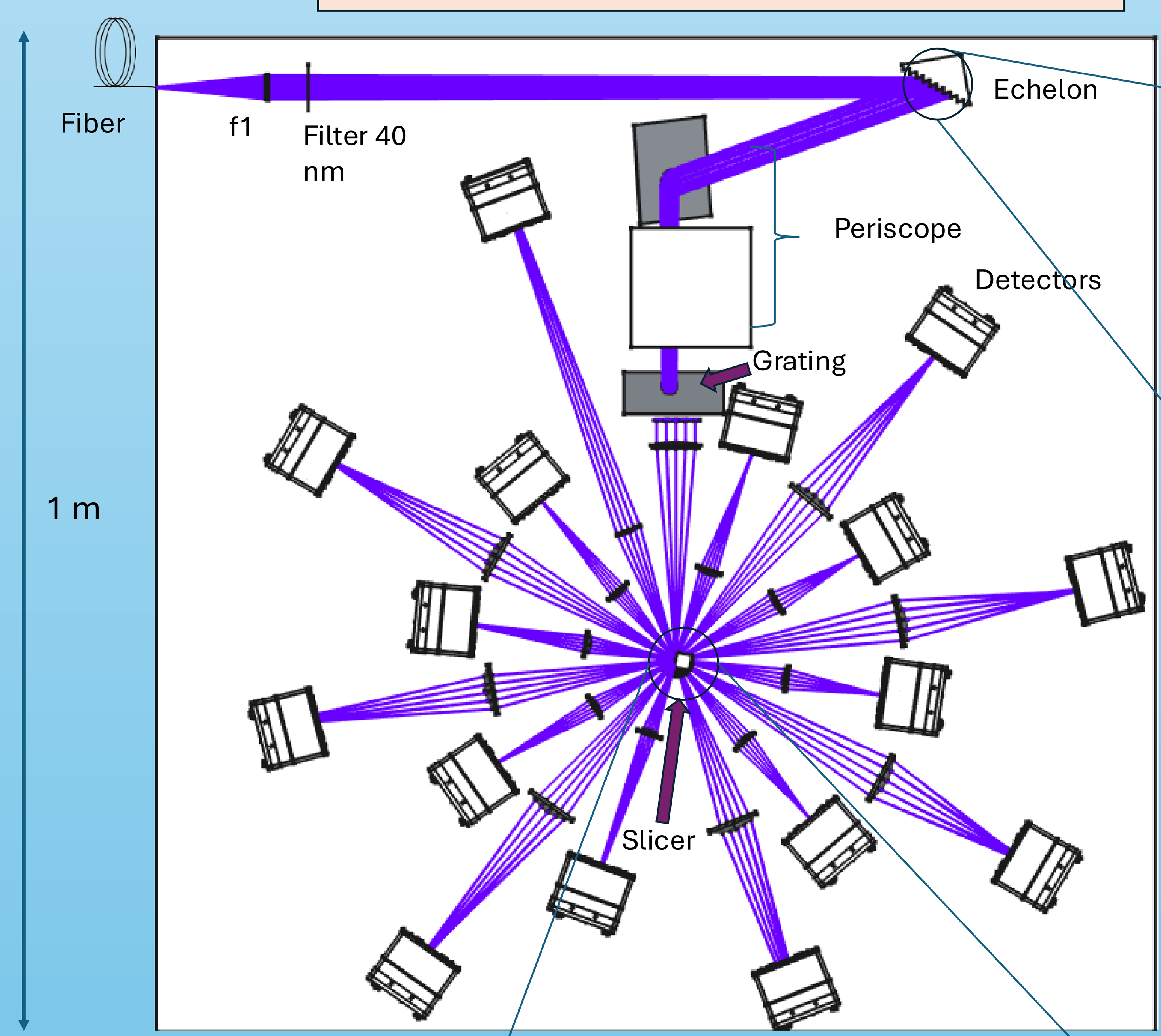
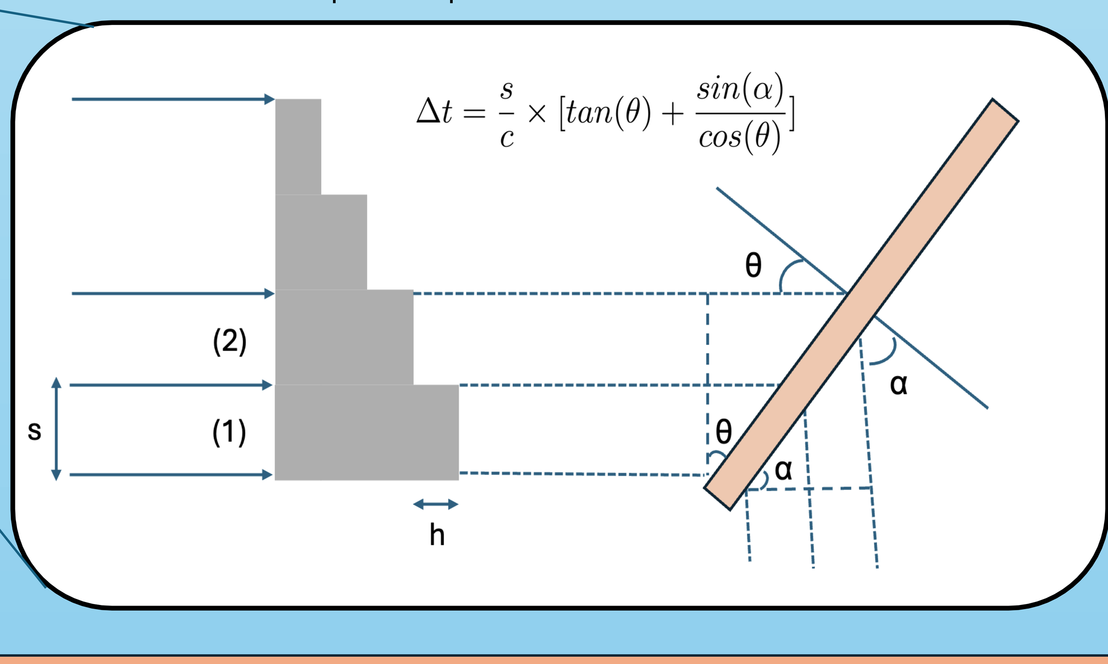


Fig. 1: A first mechanical design of the instrument

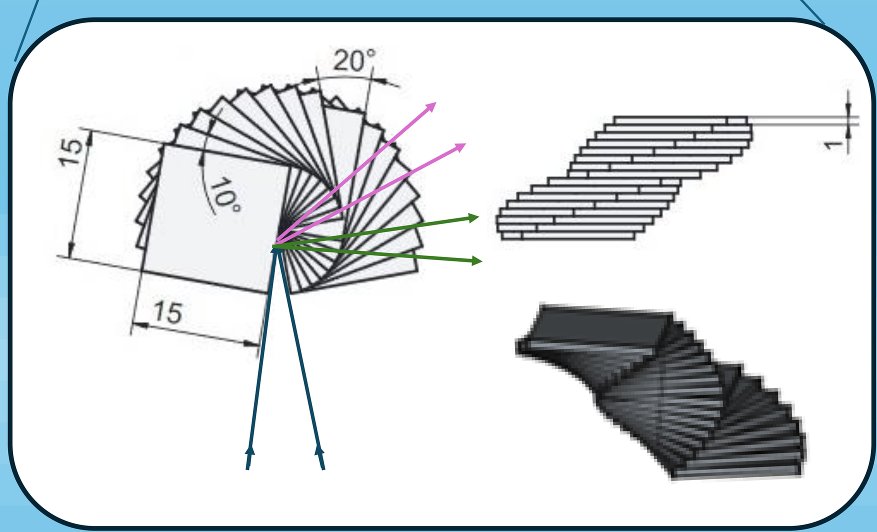
Fig. 2: Schema of an echelon in transmission for compensating dispersion of a grating. The formula gives the residual temporal dispersion.



Echelon

The Echelon is a piece of glass with a stair shape aiming to **compensate the temporal dispersion** induced by the grating (Fig. 2 & [1]). We could reduce in theory from 369 *ps* the dispersion induced by the grating to 20 *ps*.
It is possible to use it in transmission or reflection. Both have benefits and drawbacks.

Fig. 3: A mechanical plan for the design of the slicer. Values except angles are in millimeter.



Slicer

The slicer is a stack of mirrors inclined in different directions. It aims at **separating and directing the different spectral channels into each detectors**.
The thickness of each layer of the slicer determines the spectrum injected in each detector. We chose 1 *mm/layer* for 0.9 *nm* per detector.

SNR formula

The SNR is estimated with the following formula [2]:

$$SNR \propto \frac{1}{2}\alpha N_{ph}(\lambda)A|V(r)|^2\sqrt{\frac{T_{obs}}{\tau_{el}}}\sqrt{N_c}$$

Simulation results

Spectrum

Fig. 4 represents the expected 16 spectra of the instrument. We remark that there is **8% of overlap** between 2 spectra. The spectrum shape is not completely square. These two effects will impact the SNR, but it is not clearly quantified yet.

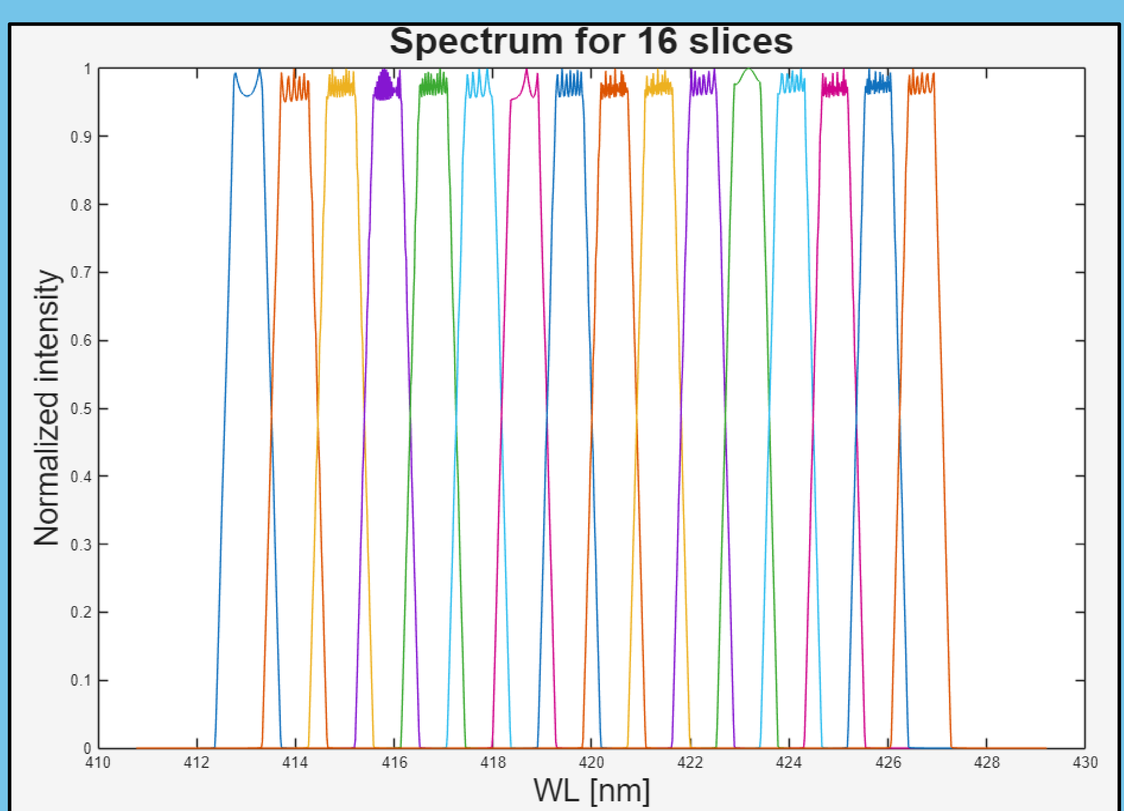


Fig. 4: Expected spectrum of the instrument for a specific configuration.

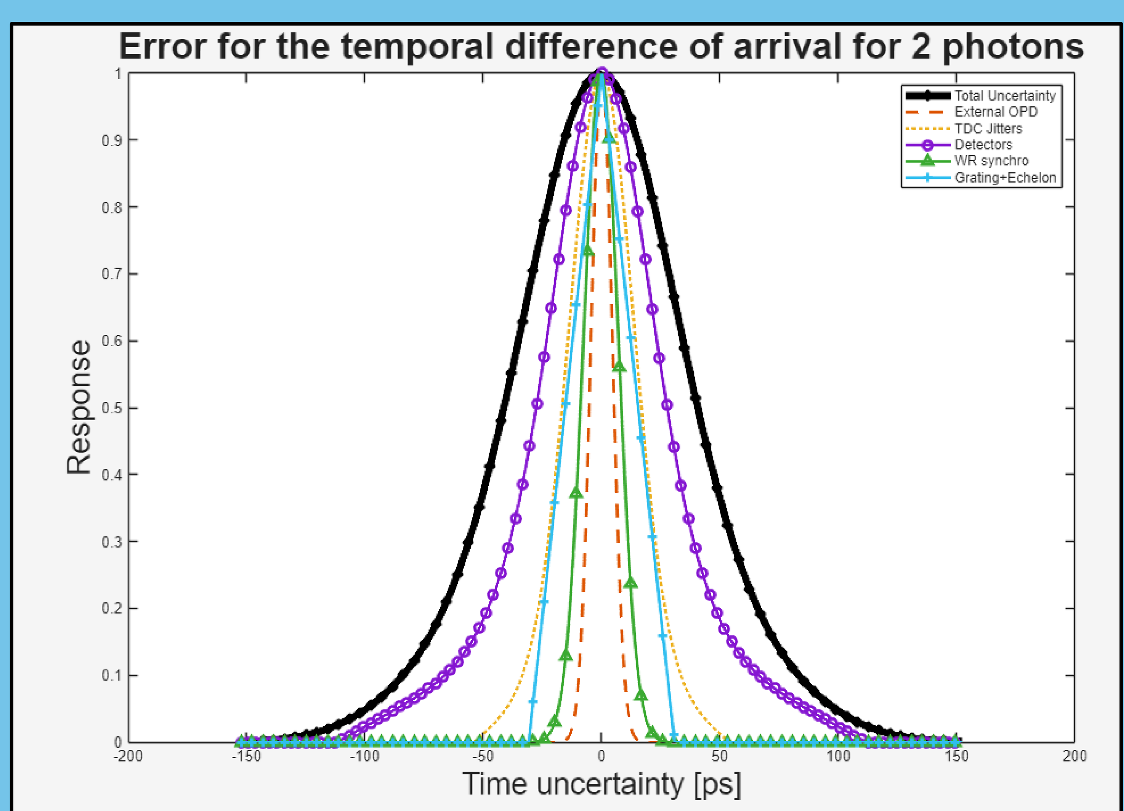


Fig. 5: Expected temporal dispersion of the different contribution and of the complete instrument.

Temporal dispersion

In Fig.5, we consider **the jitter** of the Time-to-Digital Converter (**TDC**), the one of the detectors, the compensation of the grating by the echelon, the uncertainty due to the calculation of the **external optical path difference between telescopes**. The expected FWHM is about **91 *ps***.

Conclusion

The progress of the design is an inspiring step forward. Using the SNR equation from [2], we reached **a SNR ~5 for 10 hours observation on Keck and CFHT.** The next steps are to make the different part and to test them. In particular, the slicer and the echelon are necessary pieces for successful measurements.

References

[1] Katz et al., Rev. Sci. Instrum. 87, 11E535 (2016)
[2] Guerin et al., Comptes Rendus. Phys., in press (2025);