Laboratory characterization of FIRSTv2 photonic chip for the study of substellar companions

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Introduction

Context

High contrast imaging at high angular resolution is crucial for the imaging and the spectroscopy study of faint stellar companions such as exoplanets.

To improve the angular resolution, bigger telescopes are needed. Another way to achieve higher resolution is long baseline interferometry, providing a resolution equivalent to the maximum distance between the unit telescopes (e.g. the VLTi benefits from a baseline of about a hundred meters with four ten-meter telescopes). The pupil masking [1] technique relies on a similar idea by creating a sparse aperture from a single telescope via a pupil-plane mask containing holes non-redundantly positioned.

However, by using a mask, most of the collecting area of the telescope is not used. In order to improve this aspect, the pupil remapping technique [2, 3] sub-divides the pupil using its entire surface and interferometrically re-combines the sub-pupils in a non-redundant way.

The **fibered imager for a single telescope** (**FIRST**) is an instrument developed by Paris Observatory [4, 5, 6], and currently installed on the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) at the Subaru Telescope. It aims at high angular resolution and high contrast imaging using pupil remapping with single-mode optical fibers.

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Motivation

FIRSTv2 is the upgrade of FIRST with enhanced sensitivity thanks to:
(1) optical delay lines (ODL) that equalize the optical paths,
(2) a new recombination scheme based on integrated optic chips.

This poster presents the characterization of 2 different types of photonic chips (X-coupler and Y-coupler) manufactured by Teem Photonics for their use in FIRSTv2.

FIRSTv2 scheme

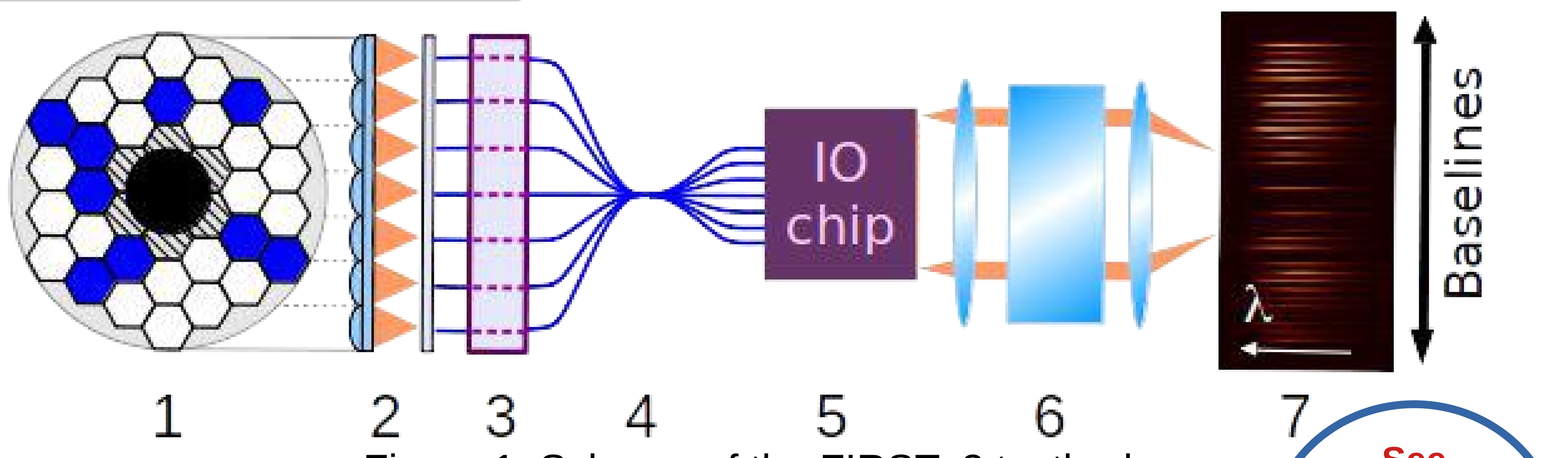

Figure 1: Scheme of the FIRSTv2 testbed

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(1) the telescope pupil represented on top of the 37-segment IrisAO deformable mirror which sub-divides the pupil into sub-pupils.
(2) the micro-lenses that inject the sub-pupil lights into (4) single-mode optical fibers
(3) ODLs allow to control the optical path length of the fibers.
(5) the photonic chip [7] performs the recombination between the sub-pupils to make them interfere
(6) the prism disperses the light before being focused onto the camera (7)

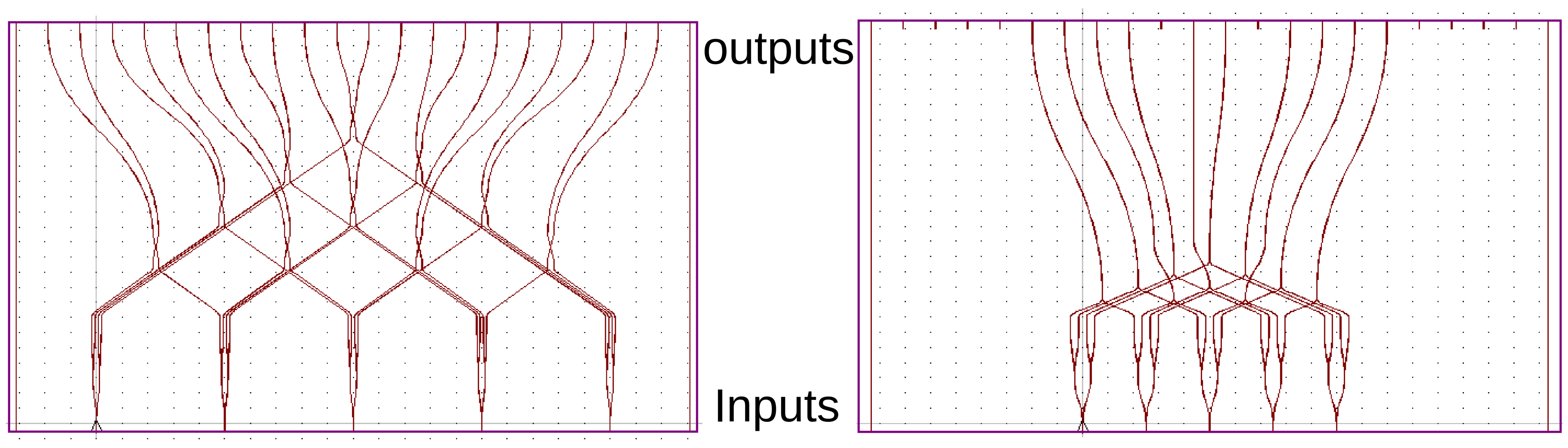

Figure 2: Schematics of the photonic chips: X-coupler (left) Y-coupler (right).
The N_i inputs are divided into N_i-1 wave-guides to interfere with all the other inputs.

The number of outputs for the 5-input X-coupler is $N_o = N_i (N_i - 1) = 20$

The number of outputs for the 5-input Y-coupler is $N_o = N_i (N_i - 1) / 2 = 10$

Photonic chip characterization

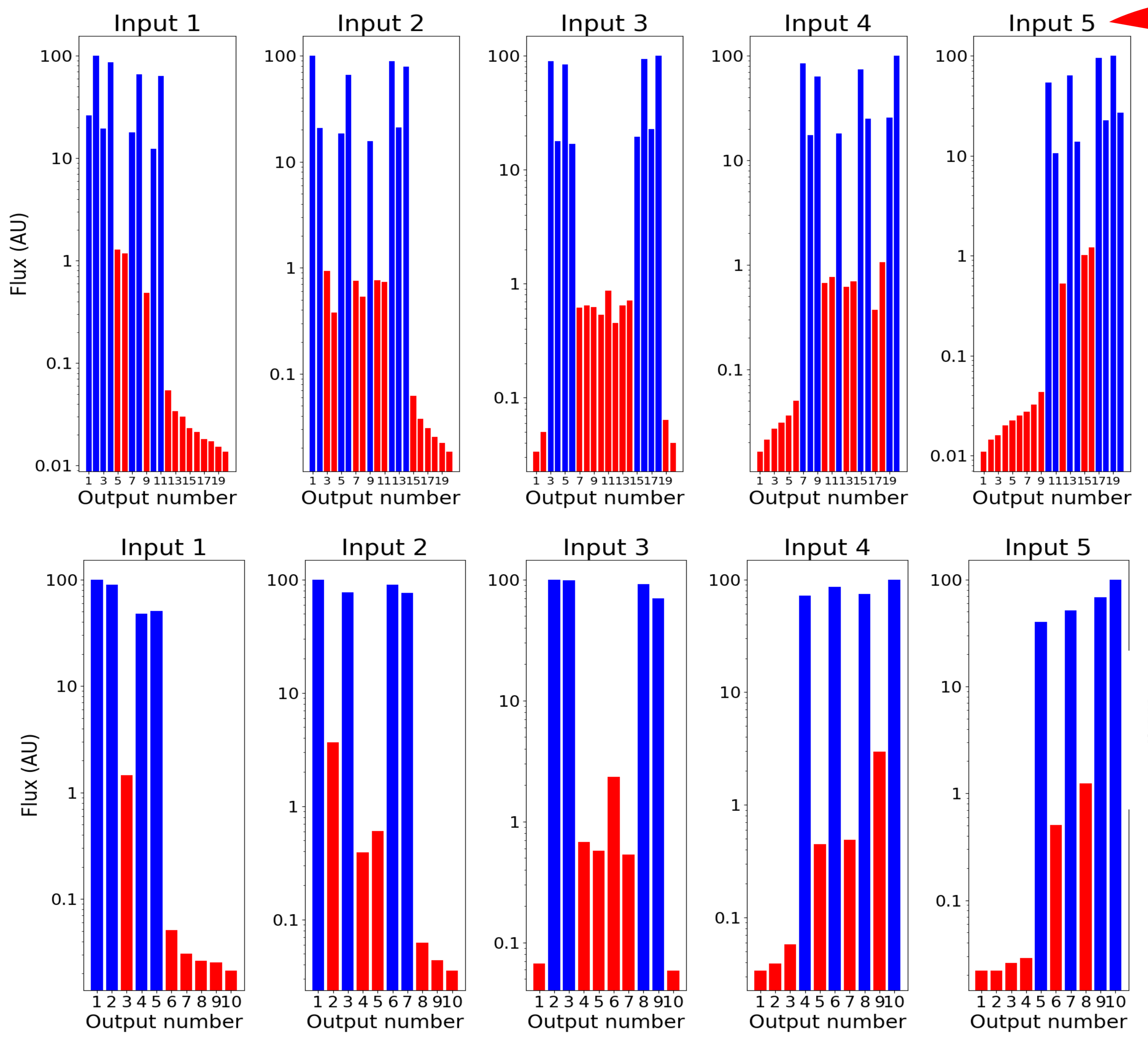

Figure 3: the flux of expected illuminated outputs (in blue) and of the expected extinct outputs (in red) for the 5 inputs illuminated individually of the X-coupler on top and the Y-coupler at the bottom

Cross-talk:
max 10% for the X-coupler
max 20% for the Y-coupler

Throughput:
~30% for the X-coupler
~13% for the Y-coupler

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left(\frac{2\pi OPD}{\lambda}\right)$$

Expected contrast assessed with: $\frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$

Contrast:
~0.8 for the X-coupler
~1 for the Y-coupler

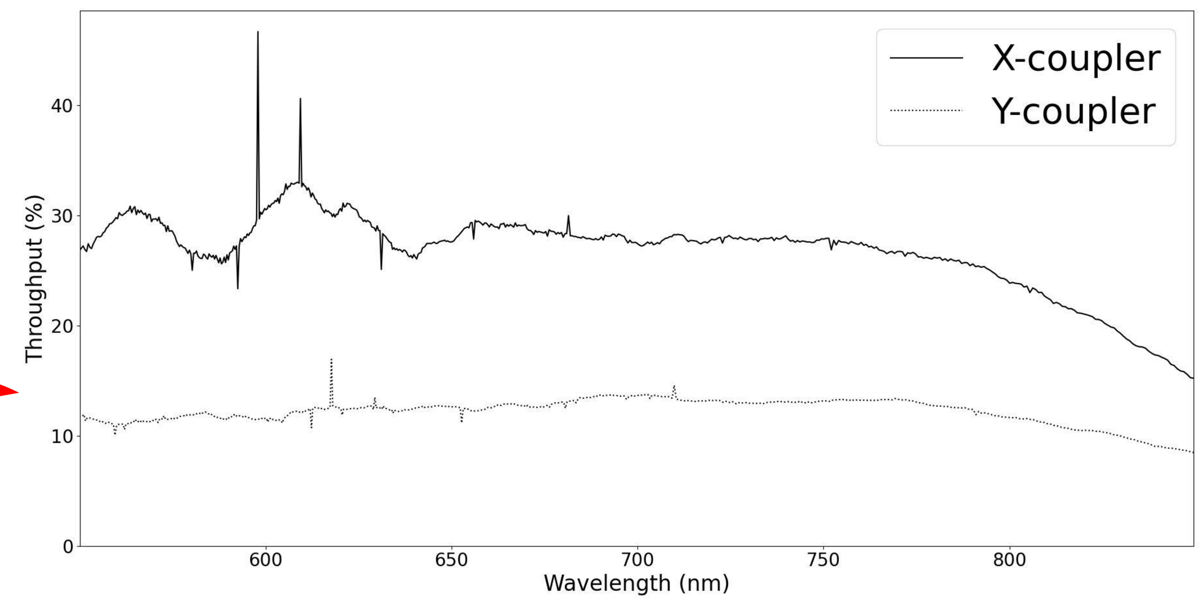

Figure 4: Plot of the measured throughput as a function of wavelength of the X- and Y-coupler in continuous and doted line, respectively.

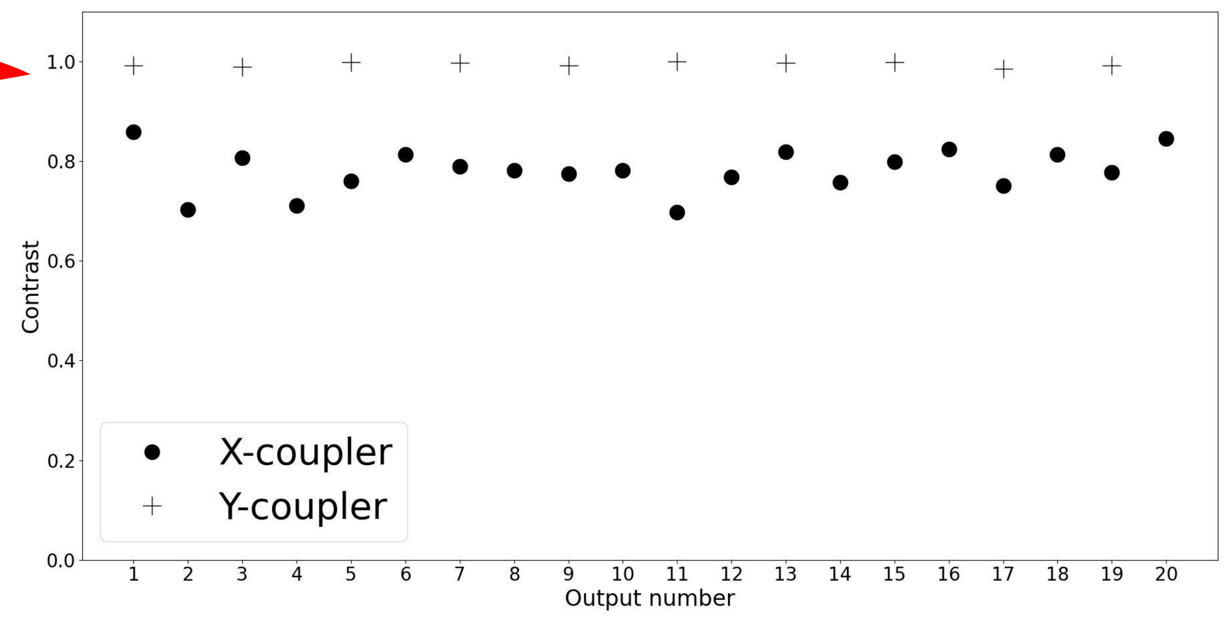

Figure 5: Expected interferometric contrasts assessed from the flux intensities of the Fig.3 as a function of the baselines for the X- and Y-coupler in dote and cross marker, resp.

Conclusion

- FIRSTv2, based on pupil remapping technique with photonic technology, is currently under lab characterization.
- The X-coupler chip is twice better in transmission than the Y-coupler, while cross-talk levels are similar.
- BUT the Y-coupler chip is expected to provide better contrast than the X-coupler chip which is a crucial specification for FIRST.

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