Multi-Wavelength Imager Concept & Specifications

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1.0 Introduction

This document presents a preliminary concept and specifications for a multi-wavelength imager (MWI) as a science instrument for ExAOC. More details on the MWI concept and relevant laboratory tests are also given in Lafrenière etal[1].

2.0 General Description of the MWI

The MWI produces 4 discrete narrow (R~30-50) band images simultaneously on the same detector enabling speckle suppression through PSF subtraction *à la* Marois etal[2] and/or the spectral "deconvolution" algorithm of Spark & Ford[3]. A crucial functionality of the MWI is to suppress speckle noise with the highest possible efficiency ideally down to the photon-noise limit. A key requirement for the MWI is to avoid the effect of non-common path optics which has been shown to be the main limiting factor of the MWI TRIDENT camera[4].

One important figure of merit for the MWI and the IFU is the noise attenuation factor τ defined as $\Delta N/N$ where N is the original PSF noise in the coronagraphic image and ΔN is the residual noise left after PSF subtraction. For example, the TRIDENT camera on CFHT achieved a τ~0.3/0.1 without/with reference star calibration. The MWI concept described here should enable τ less than 0.01 over a FOV of 5.3"x5.3". The design presented here is a slightly different (more flexible) implementation of the multi-color detector assembly (MCDA) concept[1,5,6].

3.0 MWI Concept

A 4-wavelength MWI concept is sketched in Figure 1. The output image of the coronagraph is first dissected by a lenslet array producing an array of micro-pupils. The input focal ratio is such that there is at least 2 micro-lens per λ/D, each micro-lens having a pitch of ~3 detector pixels. The micro-pupils are then reimaged through a 4-way beamsplitter combined with narrow-band filters to yield 4 PSFs images each spanning one quadrant on an IR dectector. The PSF is reconstructed by integrating the signal of each micro-pupil (see Fig. 2) over a 2x2, 3x3 pixel box or a circular aperture. Non-common aberrations are still present in this design but they affect only the shape of individual micro-pupil PSFs, the integrated signal being hardly affected. One important implementation of this design is that there is no contamination from one wavelength to another (wavelength crosstalk). Simulations have shown[6] that the speckle noise attenuation τ of the MCDA is limited by the wavelength crosstalk.

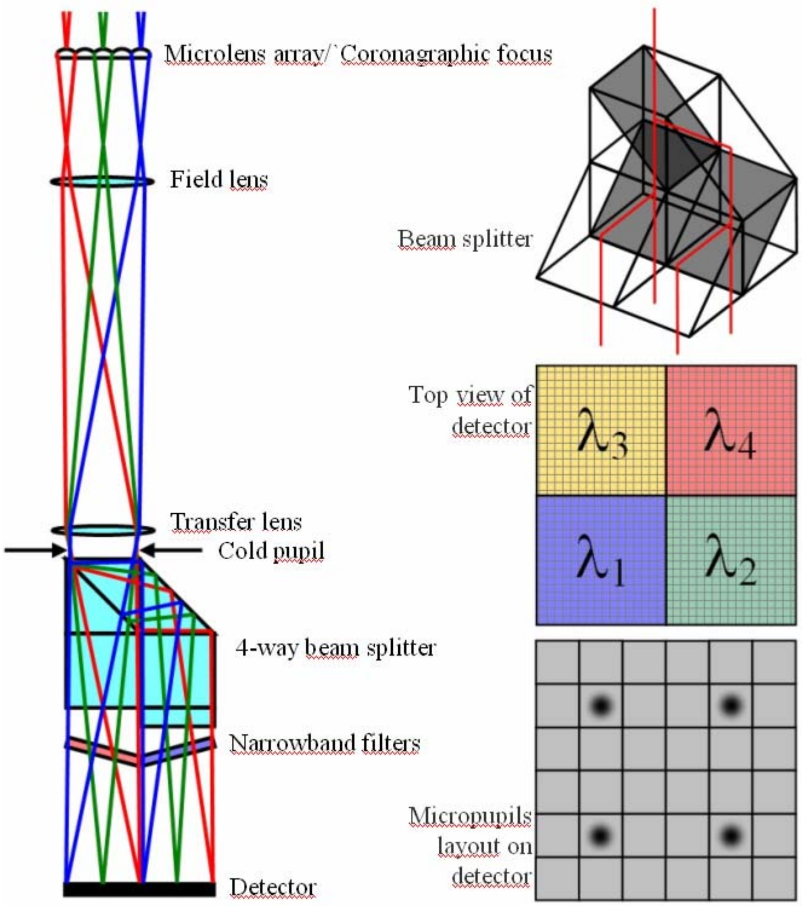

Fig.1 Multi-wavelength imager concept.

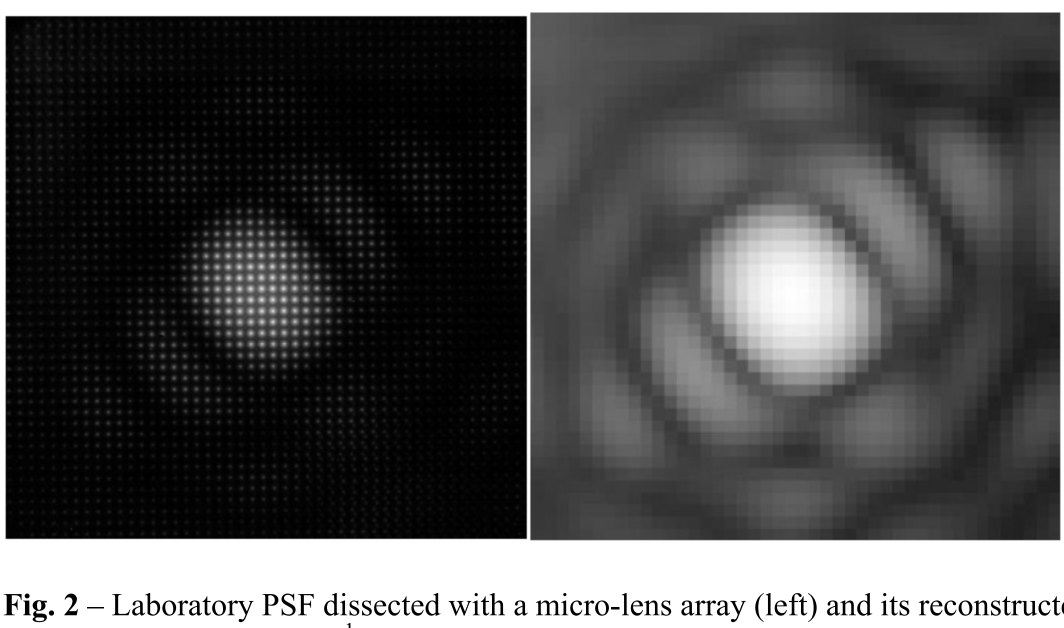

Fig. 2 – Laboratory PSF dissected with a micro-lens array (left) and its reconstructed PSF (right). See Lafrenière *etal*[1] for details.

3.1 Preliminary Optical Specifications of the MWI

The following optical specifications are adopted for the MWI study.

- **Detector:** Hawaii-2RG 2040x2040, 18 μm pixel
- **Microlens array:** square shape, 54 μm pitch (= 3 detector pixels assuming unit magnification), f/6 output corresponding to λf/D~9 μm or half a detector pixel.
- **Input focal ratio:** f/90 (2.5 micro-lens per λ/D @ 1.5 μm)
- **FOV**: 5.3"x5.3"
- **Spectral resolution:** ~50
- **Wavelengths:** 1.52, 1.58, 1.64 and 1.70 μm (see Fig. 3 below)

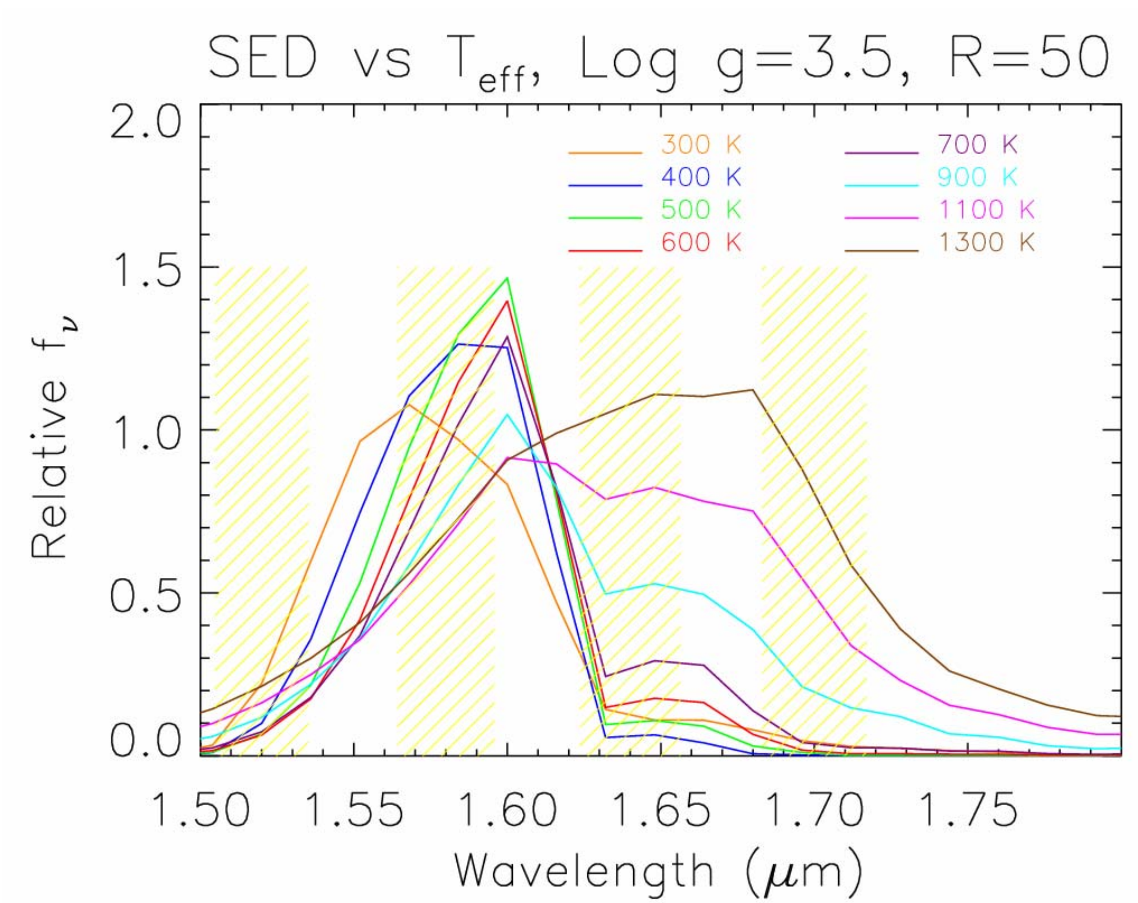

Fig. 3 – Theoretical H-band spectra of free-floating exoplanets (COND spectra from Allard *etal*, illumination from the central star excluded). The hatched yellow regions correspond to the 4 bandpass (FWHM) of the MWI. A MWI spectrum provides a good constraint of T_{eff} at a given gravity, especially at high temperature.

3.2 Dimensions and mechanical aspects of the MWI

A typical dimension between the micro-lens array and the detector is ~300-400 mm, depending on the type of transfer optics and its magnification. The MWI design has no moving part. The MWI optics, from the micro-lens array to the detector, is operated at cryogenic temperature. The micro-lens array must be kept fixed wrt the detector in order to avoid flexure-induced flatfield variations.

3.3 Beamsplitter Options

The baseline design is to use immersed dichroics (see sketch in Fig. 1) to separate all 4 beams with the maximum throughput. It is reasonable to expect throughput in excess of 70% narrow-band filters included. Another option is to use a combination of several volume phase holographic gratings to separate all channels, an idea inspired from a novel VPH-based tunable filter concept (Blais-Ouellet *etal*[7]).

3.4 Image Segmentation Options

The baseline design is to use a micro-lens array for image segmentation. An alternative option is to use an optical diffuser. If the phases introduced by a diffuser are sufficiently random, then a PSF passing through it should be relatively insensitive to non-common path optics. In principle, a diffuser should behave just like a micro-lens array. Holographic diffusers have good transmission (>85%) from UV to near-IR (1600 nm) and could probably work at cryogenic temperature (TBD). One distinct advantage of the diffuser is that it would accommodate a faster (>2x) input focal ratio and hence require a smaller detector for a given FOV. The diffuser option has yet to be studied in more details.

4 Other modes within a MWI

The beamsplitter can be made deployable to accommodate other wavebands (z, J, K). The MWI could also accommodate a polarimetric mode by replacing the 4-way beamsplitter by a 4-way polarisation beam splitter working in broad band and fed by the same transfer optics and micro-lens array. This would be a powerful mode for imaging polarized disks and suppress the non-polarized light from the central star. By extension, an IFU mode could be implemented within the same instrument.

5 References

1. D. Lafrenière, R. Doyon, R. Racine, C. Marois & D. Nadeau, *Multi-wavelength imaging concepts for exoplanet Detection, SPIE 5492, in press.*
2. C. Marois, R. Doyon, R. Racine & D. Nadeau, *Efficient Speckle Noise Attenuation in Faint Companion Imaging*, PASP, 112, 91, 2000
3. W. B. Sparks & H. C. Ford, *Imaging Spectroscopy for Extrasolar Planet Detection*, ApJ, 578, 543, 2002.

4. C. Marois, R. Doyon, R. Racine, & D. Nadeau, *Effects of Quasi-Static Aberrations in Faint Companion Searches*, EAS Publications Series 8, 233, 2003.
5. R. Doyon, D. Lafrenière, C. Marois, R. Racine & D. Nadeau, *Detecting and Characterizing Exo-planets using Multi-Color Detector Assemblies*, Proceedings SPIE "Second Workshop on Extremely Large Telescopes", in press.
6. C. Marois, R. Racine, R. Doyon, D. Lafrenière & D. Nadeau, *Differential Imaging with a Multi-Color Detector Assembly: A New ExoPlanet Finder Concept*, in preparation.
7. S. Blais-Ouellet, P.L. Shopbell, W. van Breugel, K. Taylor & R. Smith, *Double Bragg Gratings Tunable Filter for Astronony,* SPIE, 5492, in press.