Development of FIRST-IR instrument and study of nulling capabilities

l'Observatoire de Paris — LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

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Fibered Interfrometer foR a Single Telescope

- High angular resolution : **Interferometry**

  Transform a single telescope into a Fizeau interferometer

  Take advantage of the already phased beam thanks to AO system

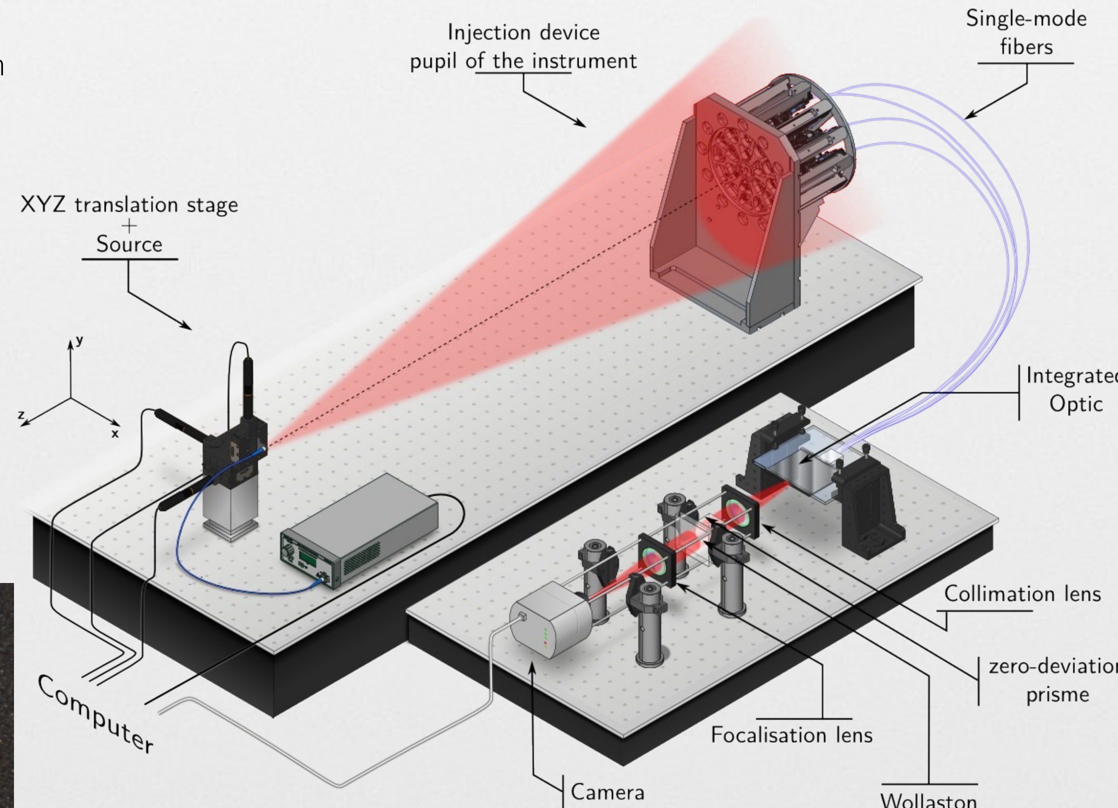
- High dynamic : **Nulling**

  Use destructive interference to “cancel” the light of the star

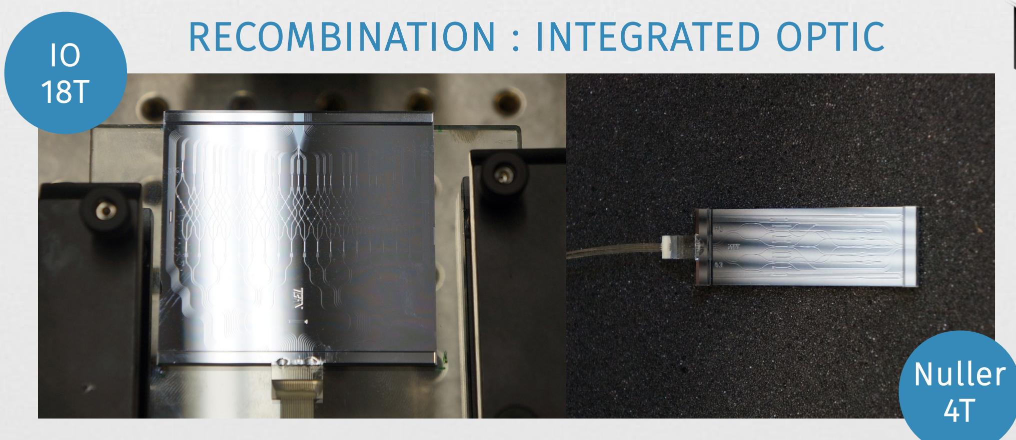
  ➡ Reduce significantly the planet/star flux ratio

  ➡ Get rid of photon noise of the star that drown planet flux out

- Working in the **H-Band** (1.55µm) ➡ **Hot Jupiters**



RECOMBINATION : INTEGRATED OPTIC



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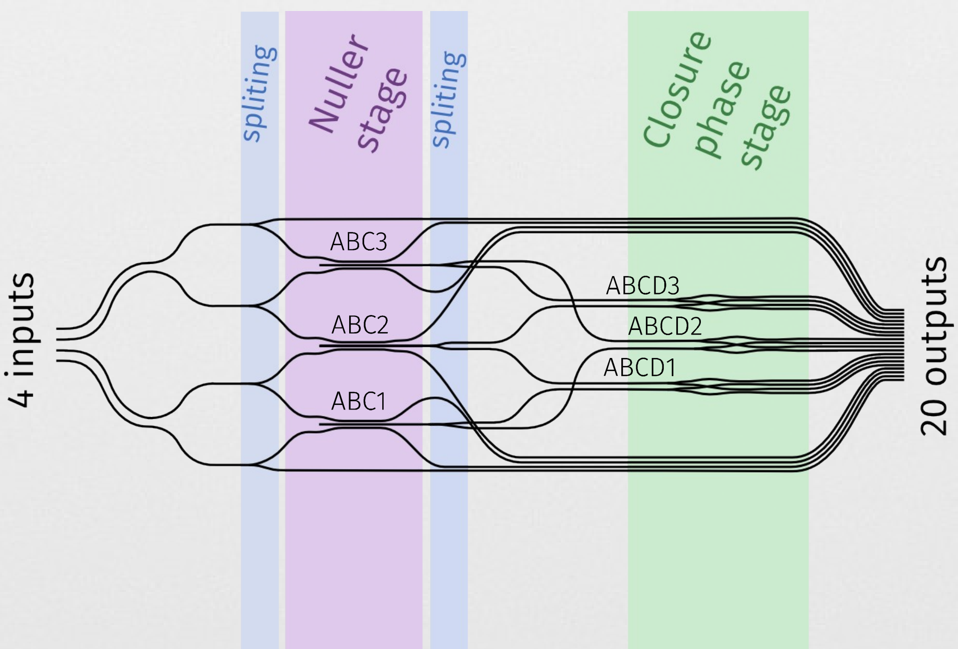
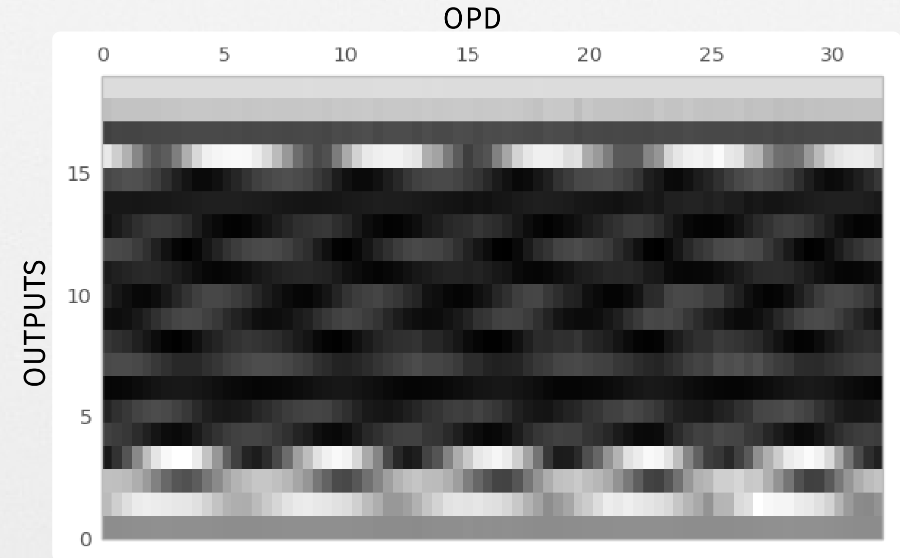
RECOMBINATION : INTEGRATED OPTIC

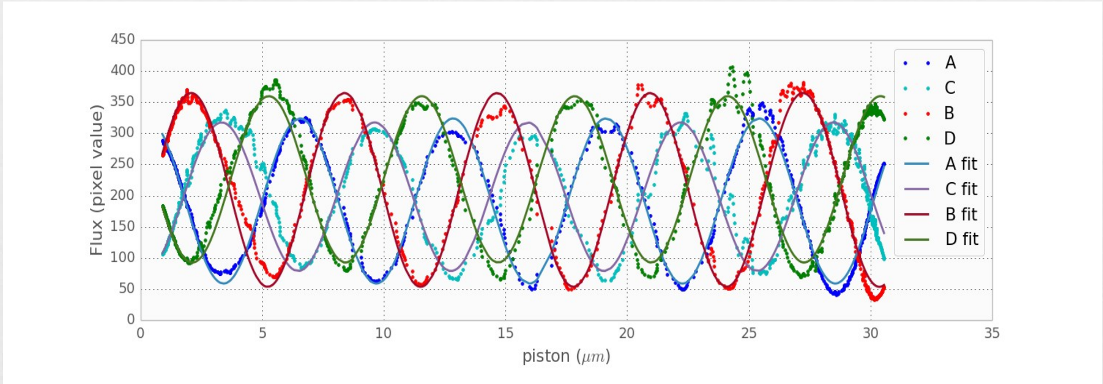
- Planar waveguides on **silicium chip**
- Single-mode polarization maintaining waveguides
- **stable – compact - easy to integrate**

NULLER

- 4 sub-pupils
- 3 ABC combiners → 3 nulls
- 3 ABCD combiners → 3 phases over the nulls



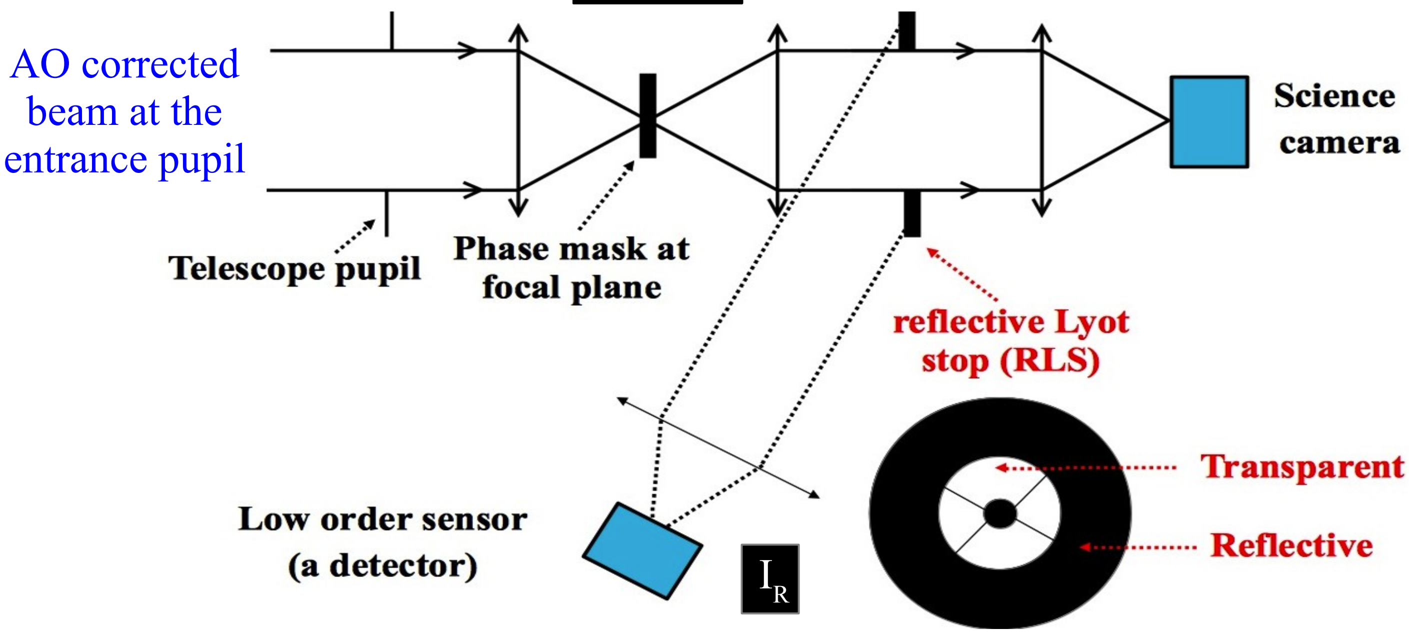




Lyot-based low order wavefront sensor (LLOWFS) for phase mask coronagraphs

Garima Singh, Olivier Guyon, Pierre Baudoz, Frantz Martinache, Nemanja Jovanovic

Principle



Assuming:

- residual phase error << 1 radian of rms wavefront error in post-AO correction.
- no correlation between low mode aberrations.

Considering only tip-tilt errors (α_x,α_y)

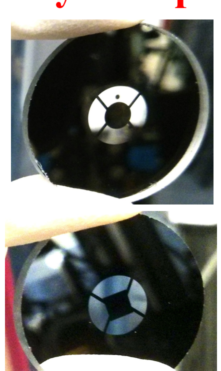
$$I_{R\,(\alpha x,\,\alpha y)} - I_0 = \alpha_x S_x + \alpha_y S_y$$

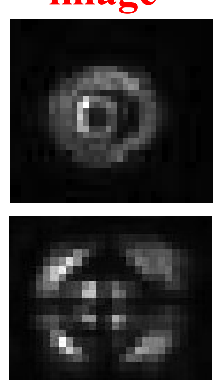
S_x and S_y : response of the sensor to the tip-tilt errors (calibration images).

(Singh et al. 2014, PASP)

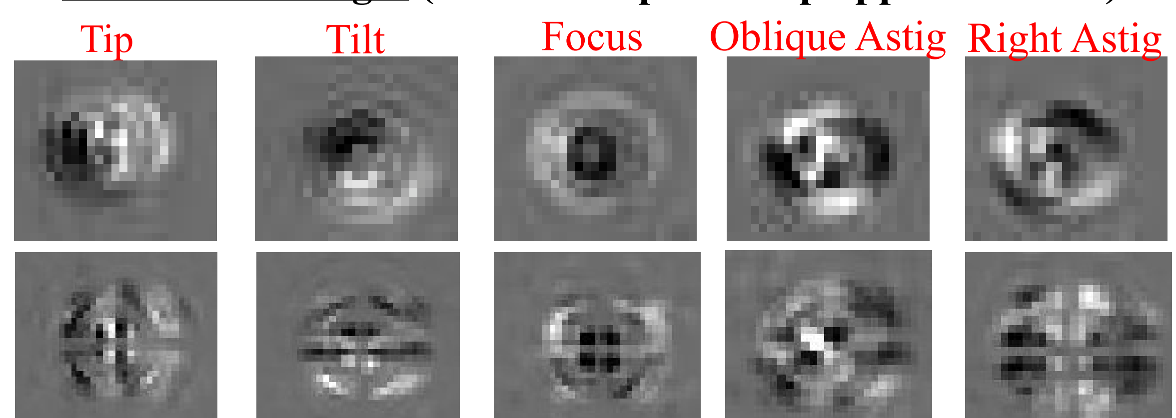
LLOWFS implementation on Subaru coronagraphic extreme adaptive optics system (SCExAO)

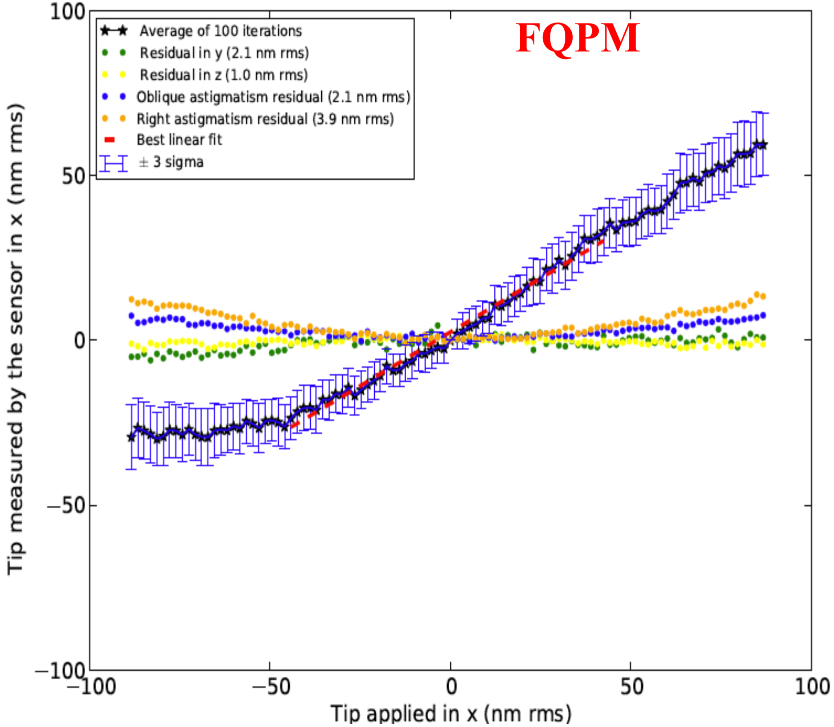
Coronagraphs	Reflective Lyot stop	Reference image
Vector Vortex (VVC)		
Four quadrant phase mask (FQPM)		





Calibration images (30 nm rms phasemap applied on DM)



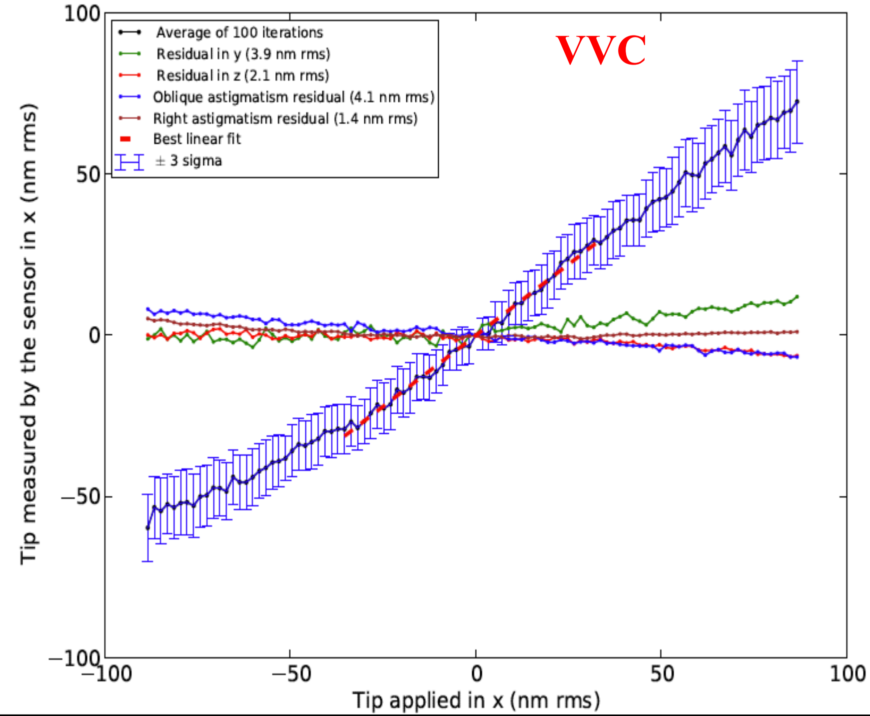


Laboratory tests

Linear response of the sensor to the tip aberrations applied on the DM

X axis : tip mode applied

Y axis : tip mode measured

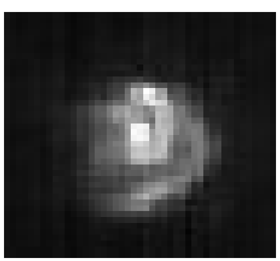


Closed loop on-sky results with VVC at H band on SCExAO at Subaru Telescope (10^{-3} λ/D closed loop accuracy)

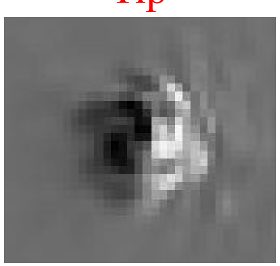
Calibration Frames on-sky

(100 nm rms phasemap applied on DM)

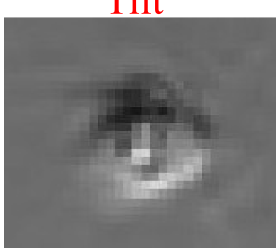
Reference frame



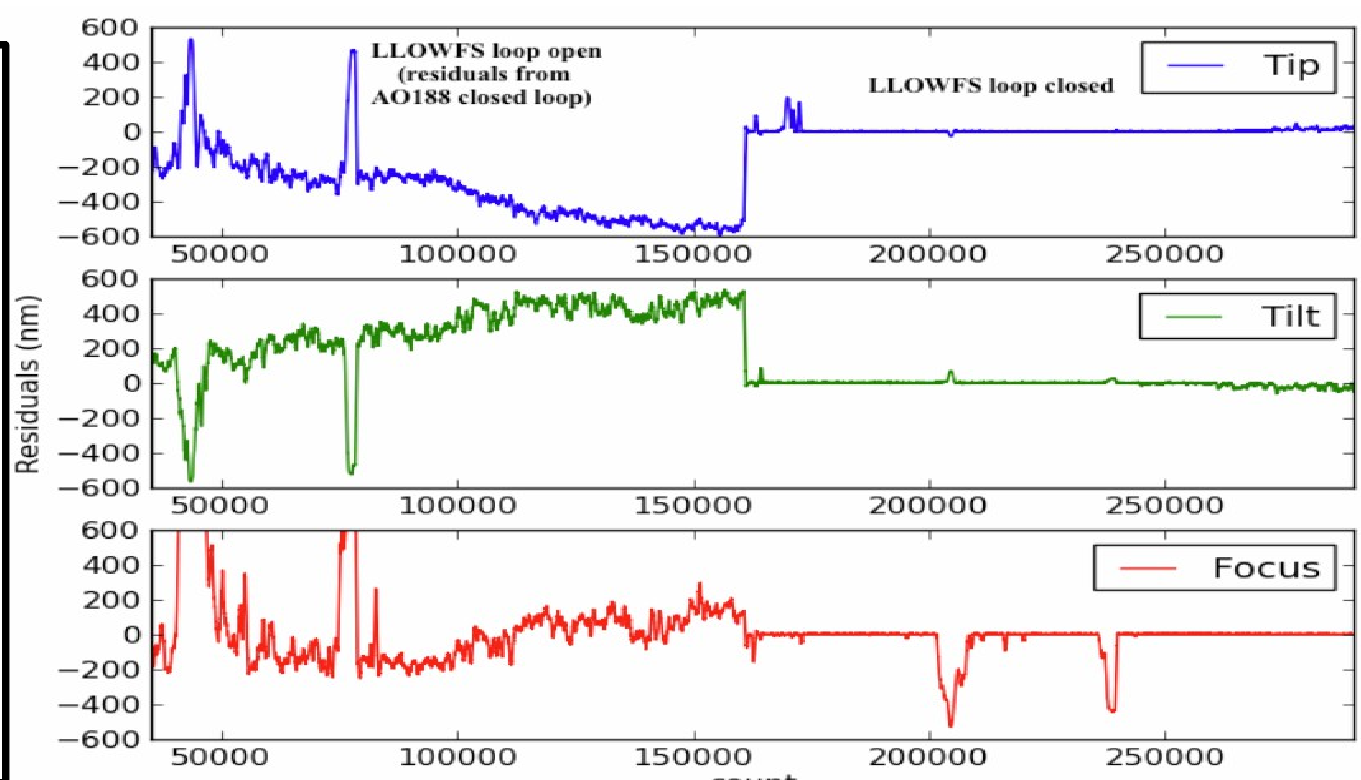
Tip



Tilt



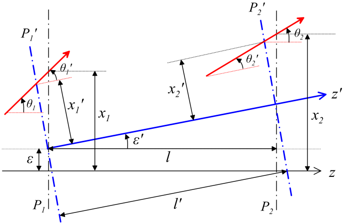
Focus

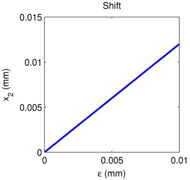


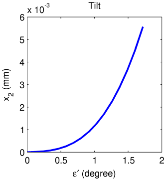
Automated optical system alignment and low-order wavefront sensing

Joyce Fang Cornell University

Method







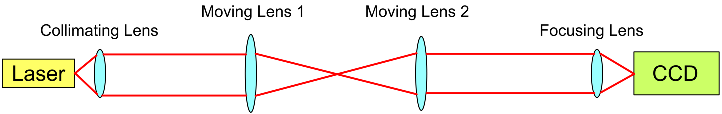
Geometric Optics:

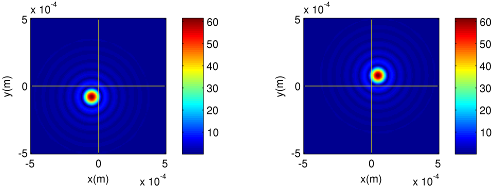
$$x_2 = \varepsilon + l \tan \varepsilon' + \left[(A + z_{add}C) \left(\frac{x_1 - \varepsilon}{\cos \varepsilon' + \sin \varepsilon \tan \theta_1} \right) + BDz_{add}(\theta_1 - \varepsilon') \right] [\cos \varepsilon' + \sin \varepsilon' \tan \theta_2] \quad (1)$$

$$\theta_2 = C\left(\frac{x_1 - \varepsilon}{\cos \varepsilon' + \sin \varepsilon' \tan \theta_1}\right) + D(\theta_1 - \varepsilon') + \varepsilon' \quad (2)$$

If we want to obtain those parameters of a given system, we will need at least two sets of intial spots (x_1, y_1) and their corresponding final images (x_2, y_2).

Experimental Setup



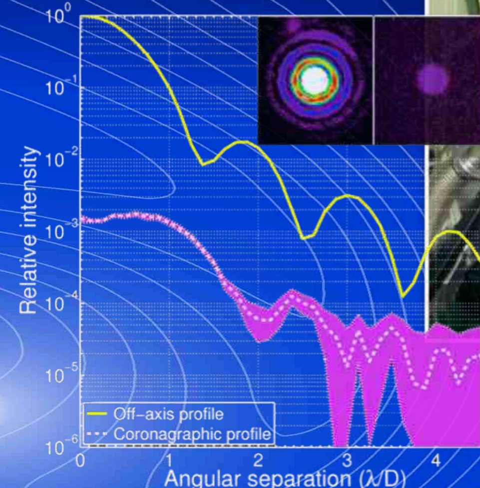


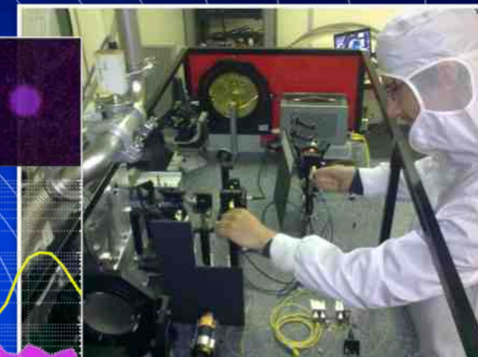
- The concept is to control the moving lenses and achieve the aligned position by feeding back the image information from the CCD camera. (Both of the moving lenses have 4 DOF, x and y-axis shift, tip and tilt.)
- If the optical system is not perfectly aligned, the CCD image will shift away from the center. The left and right images are simulated by shifting the moving lens 1 and 2 respectively.
- The center of gravity method (COG) can be used to find the shifted distances.
- Moving the lenses independently allows us to break degeneracies in the effects of misalignments of multiple lenses.

Development of a subwavelength grating vortex coronagraph of topological charge 4 (SGVC4)

Université de Liège

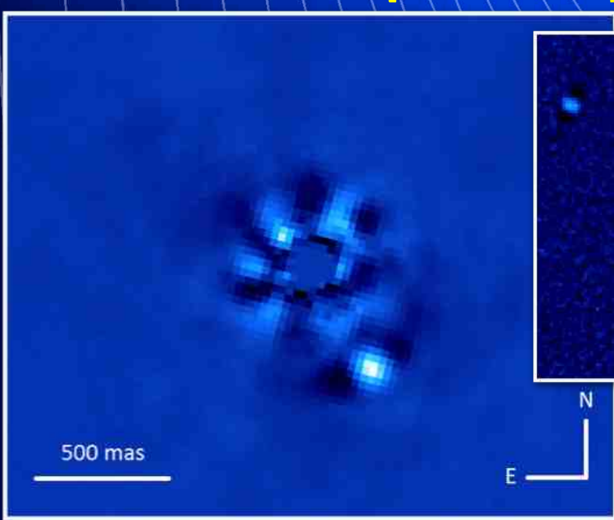
poster [9147-335] by Christian Delacroix – post-doc at U.Liège





AGPM lab demonstration
Delacroix et al. 2013

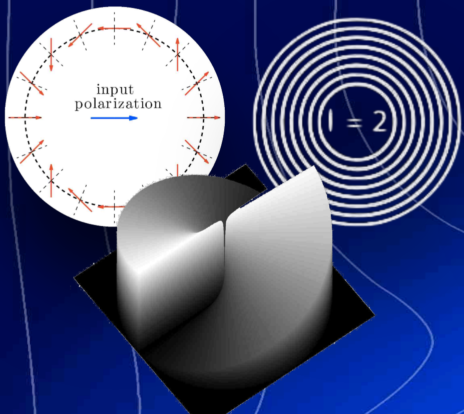
NACO-AGPM Absil et al. **[conf. 9148-21]**

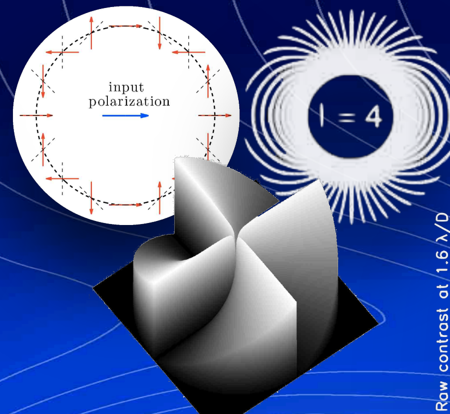


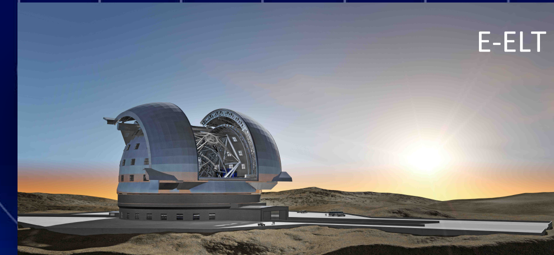
LBT/LMIRCam-AGPM
Defrère et al. **[conf. 9148-145]**

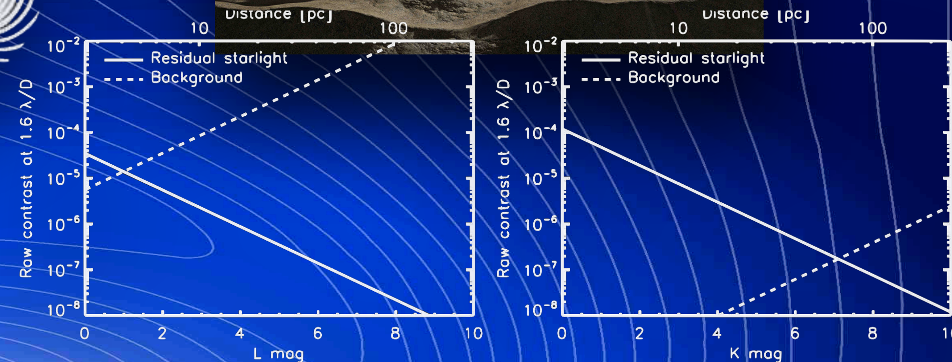
AGPM manufacturing
Forsberg et al. **[conf. 9151-44]**

From **SGVC2** (aka AGPM) … to **SGVC4**

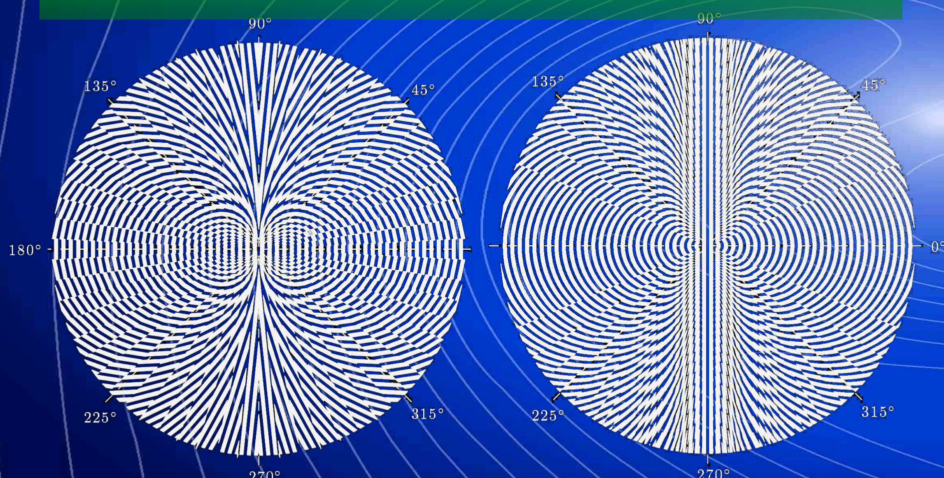


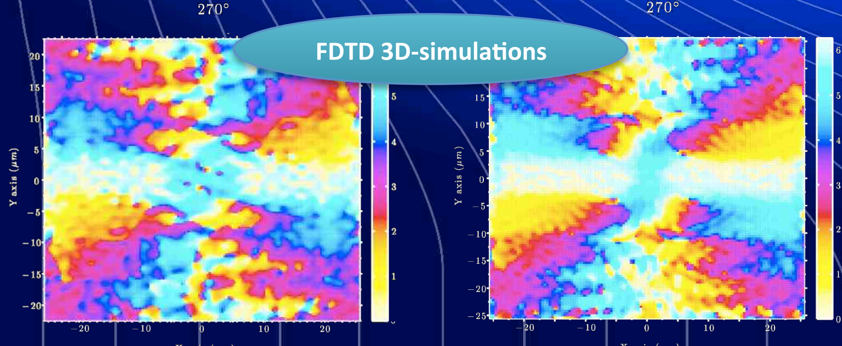






SGVC4 design: previous works **new design**





[conf. 9147-335]
SGVC4
Delacroix et al.

[conf. 9147-346]
Mid-IR AGPM designs for ELT
Carlomagno et al.

[conf. 9148-21]
VODCA – the VORTEX test bench
Jolivet et al.

CubeSat Deformable Mirror Demonstration

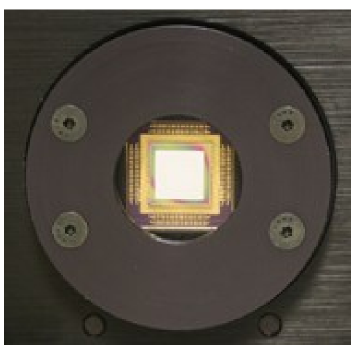
Anne Marinan (marinana@mit.edu), Kerri Cahoy

Motivation:

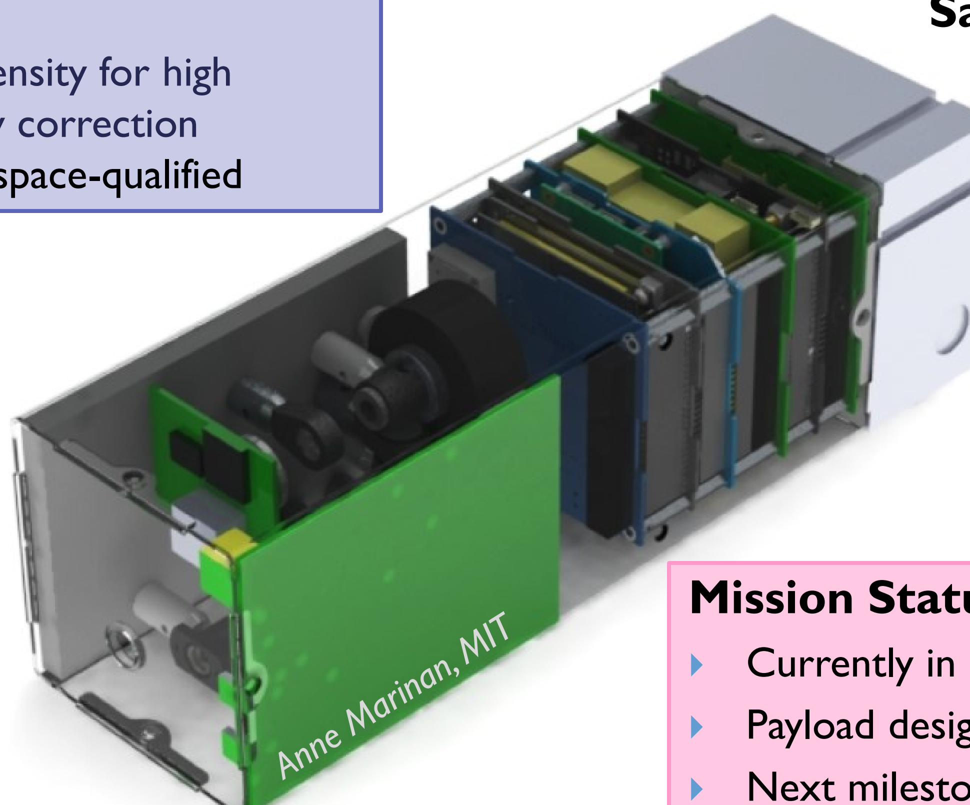
- High-Contrast Imaging in Space
  - Earth-like exoplanet imaging: 10^{-10} contrast
- Distortions → Speckles and aberrations that ruin contrast
- Wavefront control systems cancel out speckles
  - High actuator density for high spatial-frequency correction
- MEMS mirrors not space-qualified

CubeSat Mission Goals

- Achieve TRL 7 for MEMS DM
- Demonstrate image correction and wavefront sensing algorithms
- Image bright stars and other external objects



Boston Micromachines 32-actuator electrostatic Mini DM



Satellite Overview

- 3U CubeSat
  - 1.5U Optical Payload
  - 1.5U Supporting Bus
- 3-axis stabilized
- COTS components where possible
- Custom electronics interfaces with payload

Mission Status

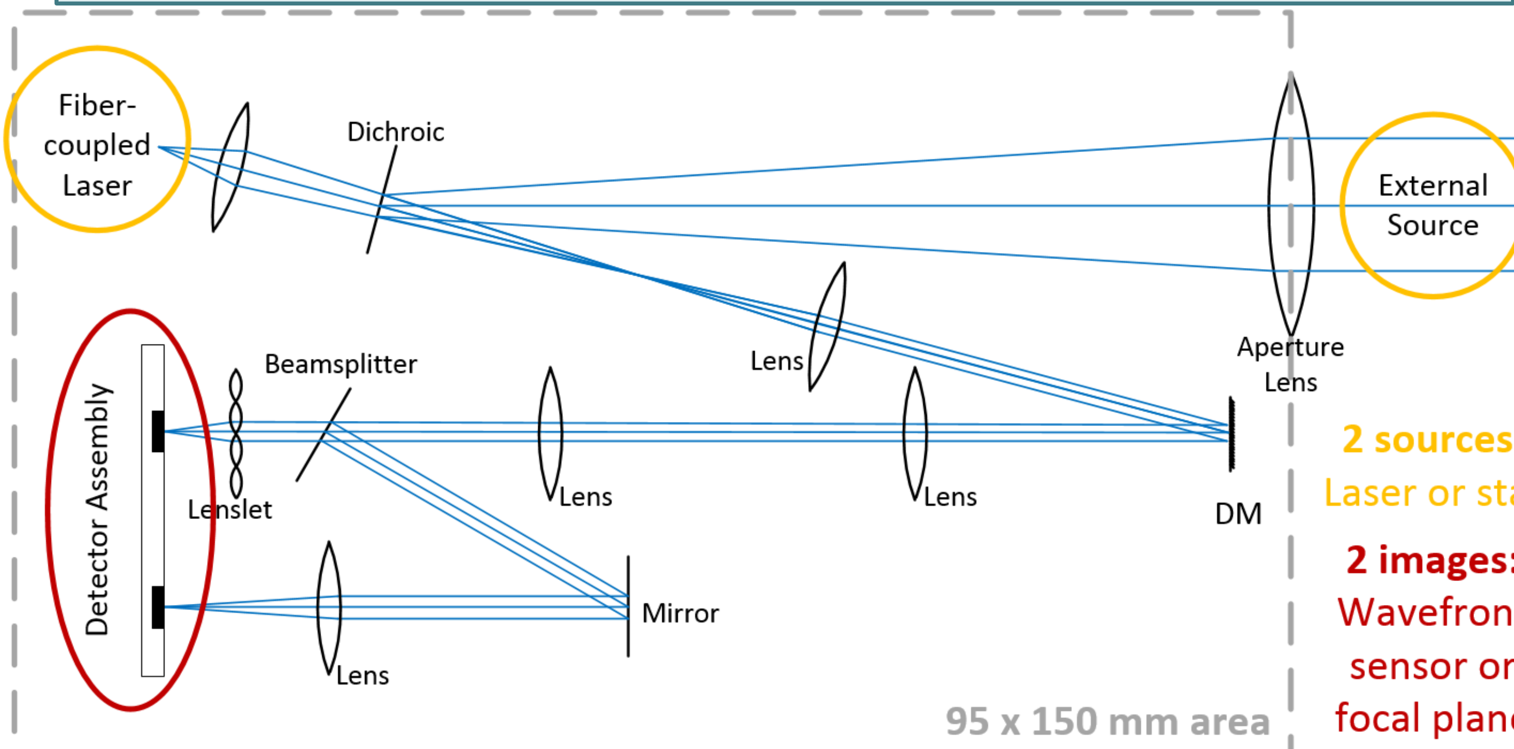
- Currently in conceptual design phase
- Payload design optimization in progress
- Next milestone: PDR in Fall 2014

This work is funded by a NASA Space Technology Research Fellowship

CubeSat Deformable Mirror Demonstration
Payload and Experiments

3 experiment architectures:

- 0 – Internal source + Wavefront sensor
  - Open-loop mirror characterization and closed loop wavefront correction
- 1 – Internal source + Focal plane image:
  - Closed loop correction with focal plane sensor
- 2 – External object + Focal plane image
  - Closed-loop image correction with focal plane sensor

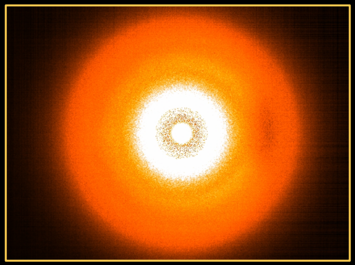


2 sources:
Laser or star

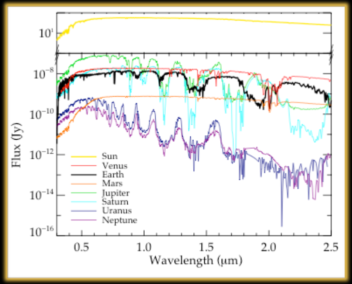
2 images:
Wavefront sensor or focal plane

This work is funded by a NASA Space Technology Research Fellowship

A High-Fidelity Solar System Model and High-Contrast Integral Field Spectrograph Prototype for Exoplanet Observations

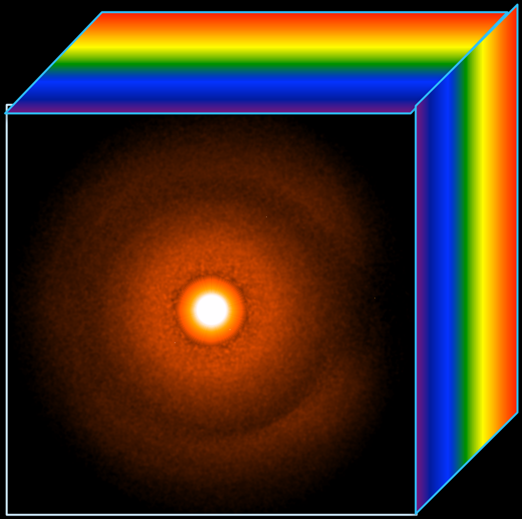


DUST



PLANETS

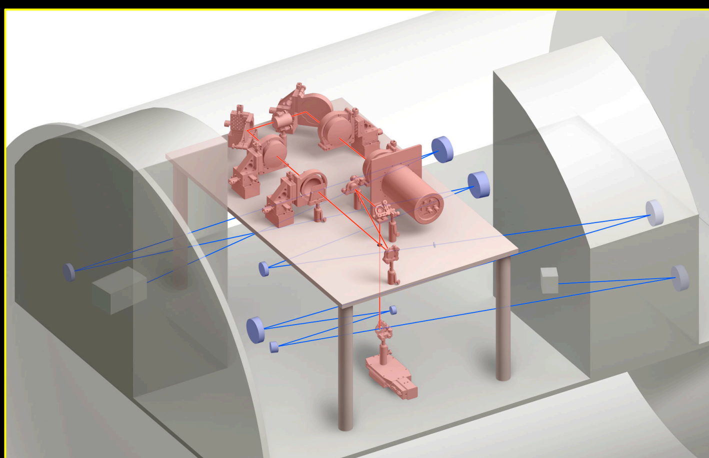
GALAXIES



Haystacks Data Cube (face-on)

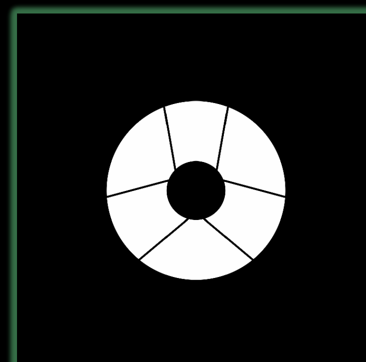
Haystacks Team: Aki Roberge (PI), Ashlee Wilkins, Maxime Rizzo, Erika Nesvold, Chris Stark, Marc Kuchner, Mike McElwain, Amber Straughn, Vikki Meadows, Ty Robinson, Tommy Wikland, Andrew Lincowski, Brittany Miles

A High-Fidelity Solar System Model and High-Contrast Integral Field Spectrograph Prototype for Exoplanet Observations

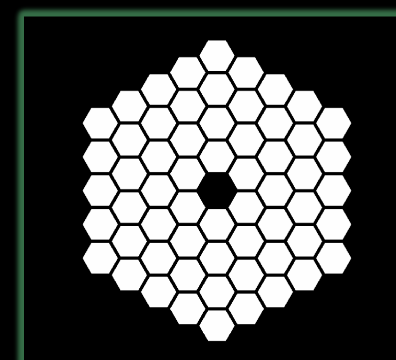


PISCES: Fall 2015 delivery to the HCIT

End-to-end testing of high-contrast instrument systems for next-generation direct imaging missions



AFTA 2.4m



ATLAST 16.8m

PISCES Team: Mike McElwain (PI), Marshall Perrin, Qian Gong, Ashlee Wilkins, Karl Stapelfeldt, Tim Brandt, Sally Heap, George Hilton, Jeff Kruk, Dwight Moody, John Trauger