SCExAO/FIRST: Interferometric spectro-imaging in visible light

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IN DEVELOPMENT

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OVERVIEW

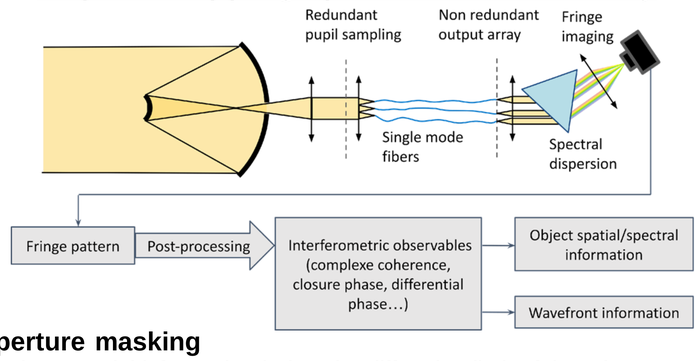
FIRST = **F**ibered **I**mager fo**R** a **S**ingle **T**elescope

Principal Investigators
Elsa Huby, Sylvestre Lacour, Guy Perrin

Subaru Local Team
Sébastien Vievard, Manon Lallement, Olivier Guyon

Photonic developments
Manon Lallement, Guillermo Martin, Harry-Dean Kenchington, Sergio Leon-Saval

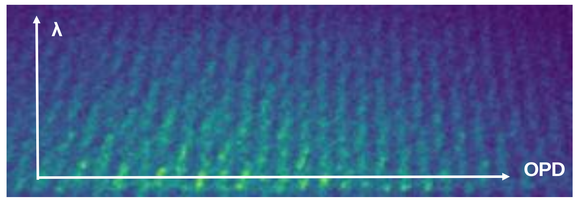
Pupil remapping spectro-interferometry



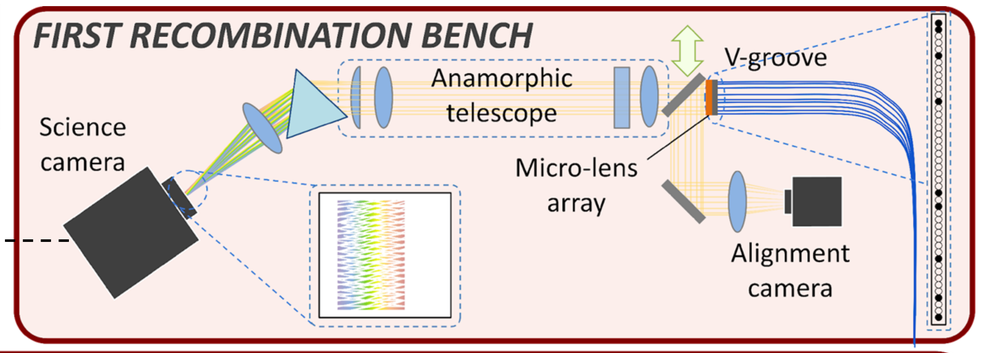
- **Aperture masking**
  Retrieve spatial information below the diffraction limit of the telescope
- **Pupil remapping**
  Aperture masking technique on the whole pupil thanks to single-mode fibers
- **Single-Mode fibers**
  Spatial filtering to remove sub-pupil speckle noise, pupil re-arrangement
- **Spectrally dispersed interferometric signal**
  Retrieve object spatial/spectral information + wavefront information

SCIENCE GOALS AND CAPABILITIES

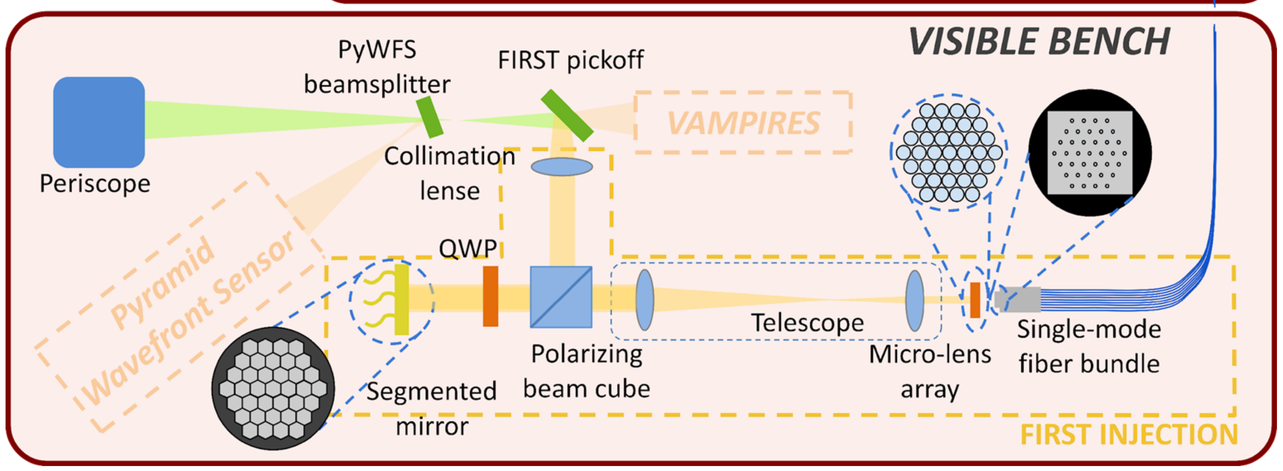
Science goals
- Detection and characterization of faint companions such as exoplanets or protoplanets
- Characterization of giant star surface



Hokulei [Capella] binary star inteferogram



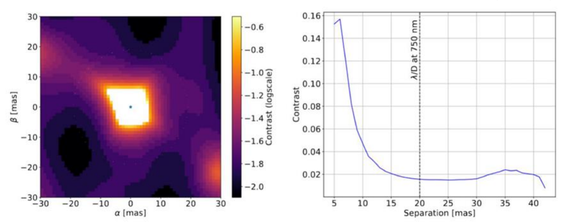
Number of sub-pupils : 9
Number of baselines : 36
Spectral bandwidth
600-800 nm
Spectral resolution
300@700 nm
Field of View
~136 mas@700 nm
Optimal field of view
20 mas@700 nm
Spatial sensitivity
down to 5 mas
Achievable contrast : $2x10^{-2}$
Magnitude limit : 3



ON-SKY PERFORMANCE

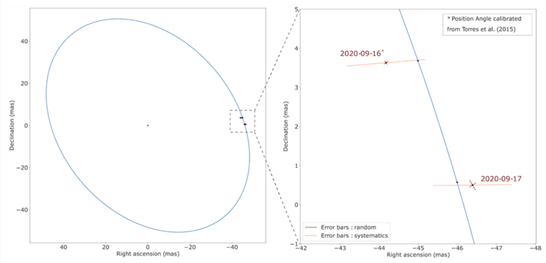
Sensitivity

Vievard et al. (A&A, 2023)



- Observation **of unresolved source: Keho`oea** [*Vega*]
- **3σ detection map** (*Left*) shows the maximal contrast achievable around the target. Best contrast here is **$8x10^{-3}$**.
- **Detection map radial value** (*Right*) shows potential detection down to **a separation of 5 mas or λ/4D at 750 nm.** Average achievable **contrast between 15 to 40 mas separation is $2x10^{-2}$**

Binary detection demonstration

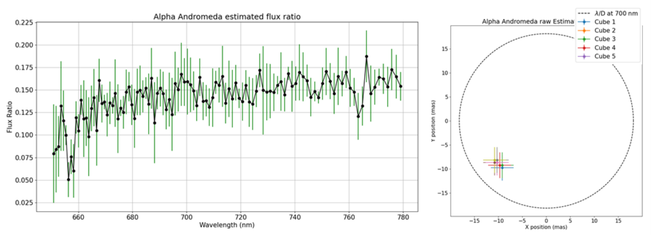


Vievard et al. (A&A, 2023)

- Observation of **« wide » binary system** : **Hokulei** [*Capella*] at 2 epochs

Date	Expected separation	Expected position angle	Estimated separation	Estimated position angle
Sept. 16th 2020	45.1 mas	274.7 degrees	44.3 ± 0.1 mas	274.7 ± 0.1 degrees
Sept. 17th 2020	46.0 mas	270.7 degrees	46.4 ± 0.1 mas	270.6 ± 0.2 degrees

Science below the telescope diffraction limit

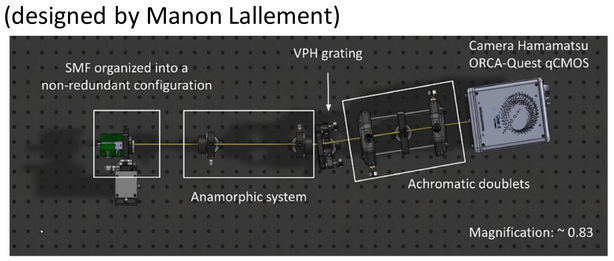


Huby et al. (in prep.)

- Observation **(S22B)** of **tight binary system : α Andromeda**
- Preliminary results show a detection of the binary component with a separation of 13.4 mas (expected is 15.4 mas) in multiple acquisitions
- Need to improve calibration, cleaning and de-rotation of the data
- Spectral extraction shows the (expected) **Hα** absorption line

LATEST UPGRADES

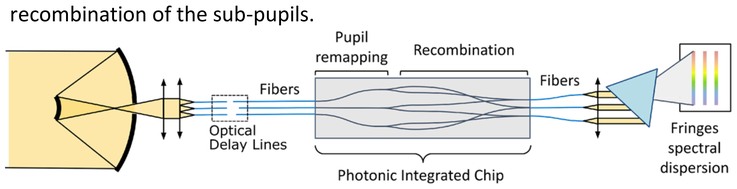
- **Injection setup upgrade (S23A)**
  1- Replacing the segmented mirror (from IrisAO to BMC)
  2- Replacing the Polarizing beam splitter with a D-mirror to improve throughput
- **Spectrograph upgrade (S23A)**
  New R-4000 spectrograph installed and validated on-sky (designed by Manon Lallement)



PHOTONICS DEVELOPMENTS

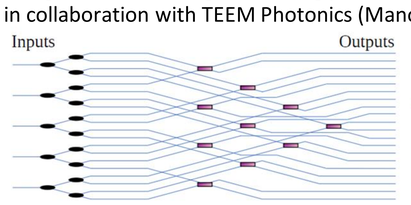
Photonic integrated chip

- **Beam combiner** : Photonic Integrated Circuit performs the pairwise recombination of the sub-pupils.



Goal : Enhance contrast and sensitivity of FIRST

- **Developments**
  Design, manufacturing and testing performed in Paris Observatory and IPAG, in collaboration with TEEM Photonics (Manon Lallement, Guillermo Martin)



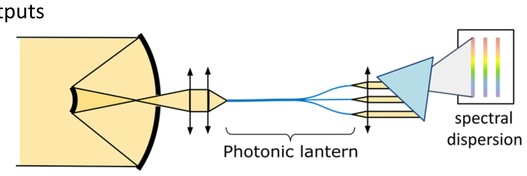
- **Splitter:** Y junction (1x2)
- **Combiner:**
  Y junction (2x1) → 10 outputs
  Directional coupler (2x2) → 20 outputs
  ABCD cell (2x4) → 40 outputs

Current PIC performance
Transmission : 30% (Goal 50 to 75%)
Cross-talk : 0.2% average (Goal <1%)

Current PIC limitations
High polarization cross-talk decreasing the overall throughput

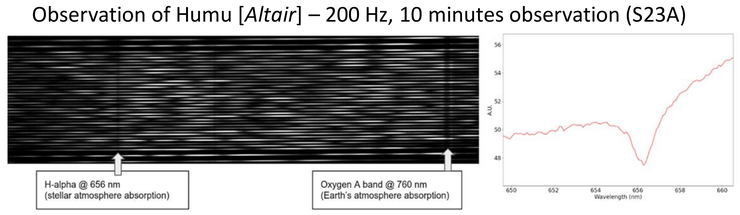
Photonic Lantern

Photonic Lantern : Fibered device with Multi-Mode input and several Single-Mode outputs



Goal : Enhance throughput of single-mode fiber-fed spectroscopy

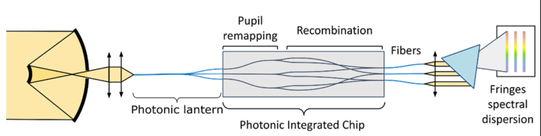
- **Status**
  A photonic Lantern feeds the FIRST R4000 spectrograph
- **On-sky testing**
  Observation of Humu [*Altair*] – 200 Hz, 10 minutes observation (S23A)



- **Current development : Optimizing injection setup for optimal use of the photonic lantern**

FUTURE PLANS

- **Upgraded spectrograph**
  - Protoplanet H-alpha emission detection
- **Photonic Integrated Chip development**
  - Increase throughput
  - → Integrate on SCExAO/FIRST
- **Photonic Lantern**
  - Instrument commissioning
  - coupling with high resolution spectrograph (R~60,000) for H-alpha line characterization
- **Photonic Lantern + Photonic Integrated Chip**
  - Feed a PIC with a Photonic Lantern



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