SPICA
Stellar Parameters and Images with a Cophased Array
Scientific context

**IF WE DON’T KNOW THE STAR, WE DON’T KNOW THE PLANETS**

- Exo earth
- Characterization
- Direct imaging
- From planets to planetary systems
- Planet and environment
- Multiscale approach
- Diversity
- Formation & evolution

Stars as Sun
- Star/planet
- Asteroseismology
- Surface imaging
- Improved modeling
- Habitability
- Diversity
- High angular resolution
The science niches of the VLT-iVis

*(Millour et al., 2018, submitted to Exp. Astr.)*

**Fundamental parameters of MS stars**

Needs: magnitude limit, high efficiency (fast!), many simultaneous baselines

**Survey of companions of close A, B stars below 30AU (current limit of AO exploration).**

Needs: limiting magnitude, high efficiency (fast!), ≥ 4 telescopes

**AGB, RSG**

Needs: snapshot imaging, (very) high spectral resolution

**Stellar environments**

Needs: snapshot imaging, (very) high spectral resolution
Summary of performance

Limiting magnitude → SNR > 10 per spectral channel, in 10mn, V=0.1

Different spectral resolutions (columns) and array configurations (rows) are considered. For each spectra resolution, we consider three modes of fringe stabilization.

<table>
<thead>
<tr>
<th>Resolving power</th>
<th>Low Resolution</th>
<th>Medium Resolution</th>
<th>High Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of spectral channel (nm)</td>
<td>300</td>
<td>3000</td>
<td>30000</td>
</tr>
<tr>
<td>Number of spectral channels</td>
<td>2</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>Total spectral band (nm)</td>
<td>150</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>N-V²</td>
<td>N-CP</td>
<td>DIT=10ms</td>
<td>Tracking DIT=100m</td>
</tr>
<tr>
<td>4 UTs, Sr=0.08</td>
<td>6</td>
<td>3</td>
<td>9.5</td>
</tr>
<tr>
<td>4 ATs, Sr=0.3</td>
<td>6</td>
<td>3</td>
<td>7.5</td>
</tr>
<tr>
<td>6 ATs, Sr=0.3</td>
<td>15</td>
<td>10</td>
<td>7.2</td>
</tr>
<tr>
<td>8 ATS, Sr=0.3</td>
<td>28</td>
<td>21</td>
<td>6.8</td>
</tr>
</tbody>
</table>

SNR=10/(Ch) V*=0.1, Tint=10mn
Statistics of the CHARA sky

High level requirements
Diameters:
- \( \text{magR}=6 \) (but at low \( V^2 \))
- High precision, high efficiency (6T)
- \( R=300 \) (LR mode)

Imaging
- \( \text{magR}=4 \) (but at low \( V^2 \))
- UV coverage (6T, +Supersynthesis)
- \( R=3000 \) (MR mode)

<table>
<thead>
<tr>
<th>( \theta &gt;0.2 \text{mas} )</th>
<th>( \theta &gt;0.7 \text{mas} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \theta ) (mas), dwarves only</td>
<td>( \theta ) (mas), dwarves only</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{Stellar populations} )</td>
<td>( \text{Stellar populations} )</td>
</tr>
<tr>
<td>( O )</td>
<td>( B )</td>
</tr>
<tr>
<td>Limiting magnitude for ( \theta &gt;0.2 \text{mas} )</td>
<td>4.3</td>
</tr>
<tr>
<td>Number of stars with ( \theta &gt;0.2 \text{mas} )</td>
<td>10</td>
</tr>
<tr>
<td>Limiting magnitude for ( \theta &gt;0.7 \text{mas} )</td>
<td>1.5</td>
</tr>
<tr>
<td>Number of stars with ( \theta &gt;0.7 \text{mas} )</td>
<td>0</td>
</tr>
</tbody>
</table>
Survey mode testing with VEGA+CLIMB 2017-10-15

10mn per star, every 15mn. Clear identification of overheads (actions in progress)

Night=115Gb ⇔ SPICA~1Tb...

No fringes drift, no pupil drifts. Only 1 NIRO alignment after a crash

Data processing in progress ➔ stability of the transfer function?
Optical design of SPICA

The two main difficulties are:
- Injection in SM fibres in partial AO correction
- Phase tracker for long exposure capabilities
Qualitative behaviour under partial correction by AO
Based on the code by Mike Ireland
~r₀=10cm, t₀=6ms
More quantitative analysis by M.A. Martinod (2018)
The CHARA Array Science Meeting 2018

Uncorrected  TelAO ON  TelAO ON + T/T

<table>
<thead>
<tr>
<th>$r_0$ (cm)</th>
<th>$&lt;\rho&gt;$ sans OA (%)</th>
<th>$&lt;\rho&gt;$ sans TT (%)</th>
<th>$&lt;\rho&gt;$ avec TT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.5 ± 0.4</td>
<td>1.37 ± 1.37</td>
<td>2.16 ± 1.85</td>
</tr>
<tr>
<td>10</td>
<td>1.3 ± 1.6</td>
<td>11.4 ± 7.49</td>
<td>16.5 ± 6.51</td>
</tr>
<tr>
<td>12</td>
<td>1.8 ± 2.2</td>
<td>21.4 ± 7.04</td>
<td>25.6 ± 5.9</td>
</tr>
</tbody>
</table>

M.A. Martinod, 2018 in progress
$r_0 = 10.6 \text{cm} - t_0 = 4.7 \text{ms}$

- no Correction
- Measure@550
- Measure@700
- Measure@950

Coupling efficiency vs Time (s)
Uncorrected  |  TelAO ON  |  TelAO ON + T/T

Visible

OA: $\rho = 0.44$
OA+TTIR: $\rho = 0.48$
OA+TTVIS: $\rho = 0.15$

H Band

TelAO ON + T/T-Vis
Design of the CESAR experiment

- PI tip/tilt system
- CHARA
- TelAO+LABAO
- Coupling efficiency
- New SPICA
- ANDOR Ixon897
SNR consideration ... long exposures ➔ Fringe Tracker

Limiting magnitude defined as S/N=10 per spectral channel in 10mn of integration

<table>
<thead>
<tr>
<th></th>
<th>R=140</th>
<th>R=3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V^2=0.25$</td>
<td>8.7</td>
<td>5.4</td>
</tr>
<tr>
<td>$V^2=0.01$</td>
<td>5.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 1: Limiting magnitude with a group delay tracker only

<table>
<thead>
<tr>
<th></th>
<th>R=140</th>
<th>R=3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V^2=0.25$, DIT=0.2s</td>
<td>10.1</td>
<td>6.7</td>
</tr>
<tr>
<td>$V^2=0.01$, DIT=0.2s</td>
<td>6.7</td>
<td>3.5</td>
</tr>
<tr>
<td>$V^2=0.25$, DIT=30s</td>
<td>10.4</td>
<td>7.1</td>
</tr>
<tr>
<td>$V^2=0.01$, DIT=30s</td>
<td>7.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Table 2: Limiting magnitude with a phase tracker

Degraded transfer function

These estimations use the same S/N calculator of FRIEND, validated on-sky.
SPICA/CHARA FT: guiding principles and baseline solution

- Do not re-invent the wheel: lessons learned from CHAMP, GRAVITY-FT
- Minimization of the development
- Full integration inside the CHARA infrastructure: a general-purpose FT if possible

- ABCD all pairs
- IO device, H band Silicium technology
- Fast and low noise detector

The solution:
- Use the H-band MIRCx fibres to feed a 6T ABCD IO component that will feed the MIRCx Selex detector
- Develop a real-time phase sensor software + a state machine to control the CHARA DL
The specifications are the following:

- Operation wavelength range: 1.5-1.8 μm (i.e., H astronomical band)
- Single-mode waveguides over the H band and with a Numerical Aperture (NA) in agreement with the standard NA of single-mode fibers: NA at 1/e²: 0.13 < NA < 0.15 at 1.55 μm in all directions
- Operation with both linear polarizations simultaneously
- Number of telescopes to be combined: 6
- Number of baselines to be coded: 15
- Type of fringe coding: ABCD coding
- Phase shift between 4 ABCD outputs: 90° +/- 10° over the whole spectral band.
- **Throughput: larger than 60% over the H band (goal: 65%)**
- Contrast level: larger than 95% in polarized light
- Flux balancing: all the outputs corresponding to one input waveguide should have the same flux over the H band. Tolerance: +/- 15%
- Flux cross-talk: below 0.5% (an input beam that is not supposed to contribute to a fringe pattern contribute to less than 0.5% of the flux)

**Pre-study made by VLC photonics**
- Technology is mature (2 or 3 different platforms)
- T between 35% and 50% (+?)
- Cost: 13k€ + 30k€ - 3-4m delay
Estimation of performance for a H-band CHARA FT

VLTI-GRAVITY FT performance

H band FT, 5 SpCh, 6T ABCD, Selex detector. T0=10ms, Texp=5/10ms
### SPICA Development Plan

<table>
<thead>
<tr>
<th>Fringe Tracker</th>
<th>SPICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Funding application (CNRS) for FT sent on 1 Mar 2018 (→ June 2018)</td>
<td>• CESAR to CHARA in June 2018. Final validation of the optical design (including or not TT mirror, sensor for TT)</td>
</tr>
<tr>
<td>• Design phase of the IO component (Summer 2018) + construction (this fall)</td>
<td>• Funding application (ANR) in Nov. 2018</td>
</tr>
<tr>
<td>• Photometric characterization at IPAG (winter 2018)</td>
<td>• Start of the detailed design by the Nice technical group</td>
</tr>
<tr>
<td>• Construction of the FT 6T testbench in Nice (beg. 2019) on the basis of the LESIA Gravity-FT table extended to 6 beams</td>
<td>(after the final delivery of MATISSE): end of 2018.</td>
</tr>
<tr>
<td>• Development of the control system, phase sensor, state machine in 2019 (based on the Gravity software)</td>
<td>• Construction in Nice from Summer 2019 to Summer 2020. Tests in Nice winter 2020</td>
</tr>
<tr>
<td>• Acceptance for departure to CHARA: Spring 2020</td>
<td>• Integration at Mount Wilson around Summer 2021</td>
</tr>
<tr>
<td>• Integration: Summer 2020</td>
<td></td>
</tr>
<tr>
<td>• 2-year postdoc funded by OPTICON (Fabien Patru, this fall)</td>
<td></td>
</tr>
<tr>
<td>• Support from Lagrange Lab in Nice for opto-mechanical interface to MIRCx</td>
<td></td>
</tr>
</tbody>
</table>

Look for alternative funding solutions at University level (end of 2018) or EU level in 2019.