A visible instrument for the VLTI

Outline

• Interest of visible wavelengths
• Is the VLTI adapted to visible interferometry?
• Context of visible interferometry and VLTI proposal
• Summary of science cases
• Principles of the instrument
• Expected infrastructure specifications
• Estimation of performances
• Next milestones
Interest of visible wavelengths

1. $\lambda \downarrow \Rightarrow \lambda /B \downarrow : \text{VLTI} @ 0.6\mu\text{m} & 200\text{m} \iff \text{VLTI} @ 2.2\mu\text{m} & 750\text{m}.$

2. Interesting to image objects at the same wavelengths than their spectroscopic or photometric studies.

3. New objects, new spectral domain ($\text{H}\alpha$), new physical processes, and new conditions are probed.

4. Because we proposed it already in 2005, and in 2011 and we are not discouraged to continue!
Is the VLTI well adapted?

- Improvements on the infrastructure (vibrations, AO/NAOMI, GRAVITY FT)
- Dense array of stations
- High number of telescopes
- Quality of $r_0$

- But limited baselines with respect to CHARA, NPOI, MROI

The limited angular resolution of the VLTI is compensated by the dense array of baselines from 8m to 140m which is critical for imaging.

The complementarity of the LSP instrumentation is also a very important aspect of the proposed science program.
Context and proposal

• VEGA and PAVO @ CHARA, VISION @ NPOI
  • Science programs on stellar fundamental parameters and spectral imaging
  • New developments around AO and monomode fibers (VISION, FRIEND) and use of up-to-date EMCCD detectors.

• Our roadmap
  • SPICA proposal on CHARA: a 6T instrument dedicated to massive survey of MS stars + surface imaging (~2019/2020).
  • SPICA will include a GRAVITY-like Fringe Tracker working in the H Band to allow long exposures.
  • Study of a HRS mode compatible with a large spectral band: Echelle spectrograph coupled with fringe sampling (SPINE).

• Our proposal for the VLTI: VLT-iVis
  • A 4T/6T/8T instrument on the same principles as SPICA/SPINE with a dedicated science case.
The science niches of the VLT-iVis (see talk F. Millour)

1. Fundamental parameters of MS stars & Giants
   Needs: magnitude limit, high efficiency (fast!), many simultaneous baselines

2. AGB, RSG
   Needs: snapshot imaging, (very) high spectral resolution

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

4. Stellar environments
   Needs: snapshot imaging, (very) high spectral resolution
The requirements of the VLT-iVis

1. Limiting magnitude,
2. High efficiency (fast!),
3. Many baselines,
4. (Very) high spectral resolution

Variability monitoring:
Dalla Vedova et al. 2017, Achernar
No disk
No disk
Disk!

Imaging surveys:
Kluska et al. 2014
Main characteristics of the instrument

• 4T (baseline) possible up to 6-8T
• Monomode fibers MIRC-like or GRAVITY-like
• Linear non redundant combination
• Dispersed fringes 600-900 nm
  - Low Resolution (R=300)
  - Medium Resolution (R=3000)
  - HR (40000) Echelle setup (?)
• “GRAVITY-like” fringe tracker
  → long exposures
  → sensitivity improvement

See Mourard et al. 2017, JOSA (just accepted)
FRIEND: a laboratory prototype…
FRIEND: installed at the CHARA array!

PhD thesis of M.-A. Martinod: Full characterization of the FRIEND/OCAM system

FRIEND sky fringes

From 2014

FRIEND lab. fringes
Injecting visible light in optical fibers

CESAR: Injection into single mode optical fibers at the focus of MéO (1.5m) equipped with ODYSSEE AO (ONERA)

Coupling \( \sim 0.1\% \)

AO off

AO on

With FRIEND@CHARA without AO, a coupling of 2.8\% has been demonstrated @700nm with a \( r_0 \) of 14cm (Martinod et al. 2017, in preparation)

New tests this year with FRIEND and the CHARA-AOs
SPINE: A spectro-interferometric echelle mode for iVis

- $R=30000$ ($\delta \lambda \leftrightarrow 0.02\text{nm} \leftrightarrow px=0.01\text{nm}$)
- Spectral domain from 550 to 850nm $\leftrightarrow 300\text{nm}$

6 T non-redundant: 18 freqs x 3 pixels x 4 fringes = 216px

17 orders Echelle Spectra
Fits to a 4096x4096 detector

Use the upcoming 4kx4k Nüvu?
**SPINE**: A spectro-interferometric echelle mode for iVis

Jan 2017: First Simulations
June 2017: Definitive design of SPINE1 test bench
Fall 2017: First Light on SPINE1
2018: Tests on SPINE1
Light transmission and data reduction
Expected infrastructure

• 4 ATs OK but full capacity with 6 or 8T. → Need more ATs. Fixed stations fine.

• UTs OK if vibration below 100 nm
  AT+UT combination up to 8T

• **Strehl on AT >30%**
  Strehl on UTs to be analyzed

• Transmission 4%, QE=90%.

• Instrumental visibility V=0.8
Expected performance on $V^2$ measurements

4 ATs, $S_r=30\%$, $R=300$, $V^*=0.1$, 10mn of integration, S/N for 1 spectral channel

Definition of limiting magnitude for S/N=10
Rmag 7.5 (coherencing) to 10 (30s cophased integration)
Summary of performance

Limiting magnitude $\rightarrow$ 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>
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<tbody>
<tr>
<td>300</td>
<td>3000</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td>Width of spectral channel (nm)</td>
<td>2</td>
<td>0,2</td>
<td>0,02</td>
</tr>
<tr>
<td>Number of spectral channels</td>
<td>150</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Total spectral band (nm)</td>
<td>300</td>
<td>100</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N-V^2</th>
<th>N-CP</th>
<th>4 UTs, Sr=0.08</th>
<th>4 ATs, Sr=0.3</th>
<th>6 ATs, Sr=0.3</th>
<th>8 ATs, Sr=0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIT=10ms</td>
<td>Tracking DIT=100m</td>
<td>Tracking DIT=30s</td>
<td>Tracking DIT=100m</td>
<td>Tracking DIT=30s</td>
<td>Tracking DIT=100m</td>
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<tr>
<td>6</td>
<td>3</td>
<td>9.5</td>
<td>10.7</td>
<td>12.1</td>
<td>7.0</td>
</tr>
<tr>
<td>7.5</td>
<td>8.7</td>
<td>10.2</td>
<td>3.6</td>
<td>4.7</td>
<td>6.3</td>
</tr>
<tr>
<td>7.2</td>
<td>8.3</td>
<td>9.8</td>
<td>3.1</td>
<td>4.2</td>
<td>5.8</td>
</tr>
<tr>
<td>6.8</td>
<td>7.9</td>
<td>9.5</td>
<td>2.8</td>
<td>4.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

$SNR=10/\text{(Ch)} V^*=0.1, T_{int}=10\text{mn}$
The critical aspects of the VLTI-Vis proposal and their status (red/orange/green)

- Status of VLTI infrastructure for visible wavelengths.
- Near IR Fringe tracking
  Tests programmed with FRIEND/CHARA

- Deeper evaluation of science programs:
  high level requirements spectral resolution, limiting magnitude.
- EMCCD: OCAM2 OK but cosmetics and size issues.
  Nuvu512 will be tested by the end of 2017

- Injection in single mode fibers: validation with CESAR,
  Tests ongoing with FRIEND and CHARA.
  Optimization in development.
- Birefringence of fibers: PIONIER-like solution validated
- Data flow definition and experience on VLT-iVis like data processing
Next milestones

• Precision on interfaces
  • Request for precise AO visible performance estimations
  • Hypothesis on transmission
  • Time scale of developments: 3rd generation or visitor instrument
• Development of the science cases to precise the high level specifications. We need inputs!
• SPICA @ CHARA development
  • Including control of injection, fringe tracking, and survey management
• R&D on SPINE
  • Tests on SPICA@CHARA
• Build the VLTI instrument
Thank you!

10-13 July 2017 : Physics of evolved stars conference
https://poe2017.sciencesconf.org

24-29 Sep. 2017 : Roscoff school
https://ees2017.sciencesconf.org/?lang=en

4-6 Oct 2017 : Asteroseismology & Interferometry workshop
https://asterinter2017.sciencesconf.org/