SPICA: a new visible combiner for CHARA

Signed by many colleagues!
Summary of the previous seasons

- 2012: VEGA limitations (intensified CCD+multispeckle) + Prospect on CHARA/AO + Progresses on EMCCD ➔ propositions P. Béroio (FRIEND)

- 2013-2015: FRIEND development and tests
- 2015: first discussion at Atlanta
- 2016: Visible meeting after the CHARA Meeting

- 2016-2017: Definition of the SPICA proposal, funding request (5-year grant unsuccessful but local funding ok to start), project organization.
Conclusions of Visible day (Nice, 2016)

Today’s main points of conclusion?

- **Science**
  - Imaging/spectral-imaging
  - High-efficient 0 machine
    - Sensitivity (detector, AO, FT)
    - Simple instrument with integrated pipeline, very few modes (2-3 maximum)

- **Concept**
  - Technology ready
  - Bulk/IO: choice to be sensitivity-driven
  - Multi-axial, dispersed fringes

- **Interfaces (important for sensitivity and reliability)**
  - Pupil and image trackers, LDC
  - AO and fiber injection
  - NIR for group-delay/fringe tracker: residuals versus magnitude/r0/dispersion...

- **Control/operation/DRS**
  - To be built on previous experience (see JMC talk) and CHARA integrated
  - More automatic processes towards final products
Stellar Parameters and Images with a Cophased Array

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
SPICA science case

- Surface-brightness-color relations
- Masses
- Fundamental parameters as a function of SpTy
  - Radius
  - Effective Temperature
  - Limb darkening

\[ \text{FROM EMPIRICAL MODELS TO MEASURES} \]

- Exoplanets host stars
- Asteroseismic targets

- Original and unique support to a large panel of space missions (Gaia, TESS, CHEOPS, PLATO) and unique support for stellar masses and stellar evolutionary constraints
3 years * 70 nights = 1000 stars

- 1000 stars: 100* for spectral imaging, 200* binaries or multiple, 700* for FP
  - 5*100+10*200+2*700=3900 observations + calibrators \(\Rightarrow\) 8000 data points
  - 40 objects per night
- 2015: 187n, 4699obj \(\Rightarrow\) 16obj/n. Factor 2.5 missing

- But
  - AO \(\Rightarrow\) 75% of ‘good seeing’ conditions
  - 6T means 15V²
  - Low spectral resolution, improved number of channels, \(\lambda\)-coverage
- Probably feasible:
  - PAVO/FLUOR experience of fast shift
  - Queue scheduling and optimization
SPICA: a first synthesis

- High-efficient $\theta$/FP machine
  - Sensitivity (detector, AO, FT), Efficiency (6T)
  - Simple instrument with integrated pipeline
  - $R=100$, 600-900nm
- Imaging/spectral-imaging
  - $R=3000$ to preserve a good sensitivity
  - 6T
- $R>30000$ option for specific studies

A: a classical dispersed fringes (VEGA/MIRC/VISION) 6T
B: a more prospective HR, wide band design with Echelle Spectrograph 3-6T
C: a powerful Phase Tracker
Main points of attention

• **Sensitivity**
  – AO-Fiber coupling and V² optimization
  – Alignment control (pupil and image)
  – Simple design; choice of components, lab implementation
  – Bulk/IO choice
  – Exposure time: Group Delay – Phase tracking

• **Efficiency**
  – Fight against downtime and overheads
  – Instrument-Array interface optimization
  – Automatic execution of OB + optimized night scheduling \( f(\alpha, \delta) \)
  – ‘integrated’ pipeline
Two main drivers for performance

**Detector**
- Nuvü512 ok for Mode A, 6T, low noise, fast readout
- Nuvü1024 ok for Mode B, 3T, ~20 orders, R=30000 & Δλ=200nm + Phase Tracker #1
- IR detector for Phase Tracker (Selex?)

**Phase Tracker**
- Group Delay is mandatory
- Phase Tracker #1: DIT=200ms, λ/10 (60nm)
- Phase Tracker #2: DIT=30s, λ/4 (150nm)

→ Gravity like FT
→ IR versus Visible

**A:** LR/MR with Group Delay
**B:** HR
**C:** Phase Tracker
Expected performance (1)

• Based on VEGA/CHARA + FRIEND experience
• S/N ($V^2$) equation comes from Gordon&Busher 2012 (eq.28)

• Numerical hypothesis
  – $T_{\text{inst}}=0.01$; $T_{\text{AO}}=0.8$; $SR=0.25$; $\text{Coupling}=0.2$; $V_{\text{inst}}=0.9$
  – $\text{QE}=0.9$, $\text{RON}=0.1$, $N_{\text{dark}}=0.0002$ (NUVU)
Expected performance (2)

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

<table>
<thead>
<tr>
<th></th>
<th>R=100</th>
<th>R=3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V^2=0.25$</td>
<td>8.7</td>
<td>5.0</td>
</tr>
<tr>
<td>$V^2=0.01$</td>
<td>5.6</td>
<td>1.9</td>
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</tbody>
</table>

*Table 1: Limiting magnitude with a group delay tracker only*

<table>
<thead>
<tr>
<th></th>
<th>R=100</th>
<th>R=3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V^2=0.25$, DIT=0.2s</td>
<td>10.1</td>
<td>6.4</td>
</tr>
<tr>
<td>$V^2=0.25$, DIT=30s</td>
<td>11.4</td>
<td>7.7</td>
</tr>
<tr>
<td>$V^2=0.01$, DIT=0.2s</td>
<td>6.7</td>
<td>3.0</td>
</tr>
<tr>
<td>$V^2=0.01$, DIT=30s</td>
<td>8.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

*Table 2: Limiting magnitude with a phase tracker*

These estimations use the same S/N calculator of FRIEND, validated on-sky
Estimation of performance for a H-band CHARA FT

VLTI-GRAVITY FT performance

H band FT, 5 SpCh, 6T multiaxial, Selex detector. T0=10ms, Texp=5/10ms

Adaptation of MIRC? New system? TBD…
GRAVITY State machine. © S. Lacour
**Instrumental principle of SPICA**

- **Pickup optics**: principle of PAVO dichroics
- **Parabola + fibers + Birefringence**
- **Retro-feed of fibers for alignment (Pup+Im)**
- **Extraction of photometry**
- **Access to CHARA sources for daytime alignment**
- **FRIEND-like**

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**Combiner+Detectors**

- **Infrared injection?**
- **Visible injection**
Work breakdown (1)

1. Pre-studies on critical components
   1. Nuvu qualification + software control
   2. Evaluation of new actuators
   3. LDC check: do we need them? new glass for improved transmission?

2. Studies on critical conceptual aspects
   1. FRIEND fibers + OA injection: additional tip/tilt? Retro-lightening and direct co-alignment with CHARA?
   2. Principles for photometry extraction: pupil slicers, flux slicers, see possibilities after the fiber exit.
   3. Monitoring of seeing parameters: r0, t0
Work Breakdown (2)

3. **Science requirements and performance evaluation**
   1. FRIEND S/N values + all FRIEND parameters: SPICA S/N calculations and performance evaluation
   2. Decision on spectral resolutions
   3. Definition of observing modes
   4. SPICA large program science group organization

4. **Fringe-tracking**
   1. Design of a H-band fringe tracker optimized in terms of transmission, number of spectral channels, detector and all parameters.
   2. Continuation of performance evaluation
5. **Optical and mechanical implantation**
   1. Pupils position, OPD scheme
   2. Optical design and implementation
   3. List of optical pieces, list of mechanical pieces, list of motors and actuators
   4. How to accommodate a high spectral resolution mode: number of beams, 2\textsuperscript{nd} detector
   5. Alignment procedure, operating procedure

6. **Software architecture :**
   1. ICS FTS DCS OS
   2. Data flow of acquisition and archiving : database L0
   3. Data flow of DRS and RT-DRS : policy for L1 and L2
   4. Specifications of RT-DRS
   5. Specifications of quality check, database of quality check
   6. Automatic pipeline
   7. Operation software : queue observations, calibrator sequence
Short term activities

Continue to acquire experience with FRIEND prototype (especially AO/injection and piston)
Nuvu512 qualification/acquisition
System analysis ➔ specifications.
Implementation in the lab, general design of science light path and control systems

Funding mid-2017 ? ➔ 1st light mid-2019 (A), 2020 (B+C)