The installation and commissioning of MATISSE

The new VLTI mid-infrared instrument

Anthony Meilland
And the MATISSE commissioning team
Bruno Lopez, Stephane Lagarde, Romain Petrov, Philippe Bério, Florentin Millour, Pierre Cruzalebes, Sylvie Robbes, Fatmé Allouche, Alexis Matter...
The CHARA/NPOI Science Meeting 2019

Current Status of VLTI

4 Unit Telescopes (8.2m)
- Fixed: B = 46 – 130 m
- Equipped with 60 actuators AO (MACAO)
- Two wavefront sensors:
  - Visible: MACAO
  - Near-IR: CIAO (developed for GRAVITY)

4 Auxiliary Telescopes (1.8m)
- Movable: B = 13 – 140 m
- Recently equipped with a AO (NAOMI)
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Current Status of VLTI

NAOMI

- Deformable Mirror
  - ALPAO DM241

- Wavefront Sensor
  - 4x4 Shack–Hartmann

  Installed in September 2018
  Commissioned in fall 2018

  Improve the limiting magnitude (1mag)
  Faster object acquisition (<2min)
Current Status of VLTI

Installation of MATISSE warm-optics in the VLTI Lab (November 2017)

<table>
<thead>
<tr>
<th>nTel</th>
<th>Band</th>
<th>Spectral Res.</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDI</td>
<td>2 N</td>
<td>20-230</td>
<td>2001-2015</td>
</tr>
<tr>
<td>AMBER</td>
<td>3 (J)HK</td>
<td>30-12000</td>
<td>2003-2018</td>
</tr>
<tr>
<td>PIONIER</td>
<td>4 H</td>
<td>5-30</td>
<td>2010</td>
</tr>
<tr>
<td>GRAVITY</td>
<td>4 K</td>
<td>22-4000</td>
<td>2016</td>
</tr>
<tr>
<td>MATISSE</td>
<td>4 LMN</td>
<td>30-4000</td>
<td>2018</td>
</tr>
</tbody>
</table>
Current Status of VLTI

AMBER and MIDI deserve their retirement

![Pie chart showing instrument usage]

Interferometric papers by instrument
(source: JMMC bibDb)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>nTel</th>
<th>Band</th>
<th>Spectral Res.</th>
<th>Available</th>
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<tbody>
<tr>
<td>AMBER</td>
<td>3</td>
<td>(J)HK</td>
<td>30-12000</td>
<td>2005-2018</td>
</tr>
<tr>
<td>PIONIER</td>
<td>4</td>
<td>H</td>
<td>5-30</td>
<td>2012</td>
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<td>MATISSE</td>
<td>4</td>
<td>LMN</td>
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<td>2019</td>
</tr>
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</table>
MATISSE : a lot more than MIDI successor!

<table>
<thead>
<tr>
<th>MIDI</th>
<th>MATISSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Telescopes</td>
<td>4 Telescopes</td>
</tr>
<tr>
<td>Co-axial</td>
<td>Multi-axial</td>
</tr>
<tr>
<td>N band</td>
<td>L&amp;M bands</td>
</tr>
<tr>
<td>8-13µm</td>
<td>3-5µm</td>
</tr>
<tr>
<td>R = 30, 230</td>
<td>R = 34, 506, 950</td>
</tr>
<tr>
<td>Raytheon IBC</td>
<td>HAWAI-2RG</td>
</tr>
<tr>
<td>320x240</td>
<td>2048x2048</td>
</tr>
</tbody>
</table>

Pierre Antonelli (Project Manager), Bruno Lopez (PI), and Philippe Berio (DRS) in the MATISSE integration room in Nice
The science cases of MATISSE

- Study temperature and density profile in the disk (in continuum L,M, and N bands)
- Detect gaps and other structures in the disk
- Locate chemical elements in the disk such as water, ice, CO,...

### Feature

<table>
<thead>
<tr>
<th></th>
<th>Wavelength (μm)</th>
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</thead>
<tbody>
<tr>
<td><strong>L- and M-bands (~ 2.8–5.0 μm)</strong></td>
<td></td>
</tr>
<tr>
<td>H₂O (ice)</td>
<td>3.14</td>
</tr>
<tr>
<td>H₂O (gas)</td>
<td>2.8–4.0</td>
</tr>
<tr>
<td>H lines (Br-α, Pf-β)</td>
<td>4.05, 4.65</td>
</tr>
<tr>
<td>PAHs</td>
<td>3.3, 3.4</td>
</tr>
<tr>
<td>Nano-diamonds</td>
<td>3.52</td>
</tr>
<tr>
<td>CO fundamental transitions</td>
<td>4.6–4.78</td>
</tr>
<tr>
<td>CO (ice)</td>
<td>4.6–4.7</td>
</tr>
<tr>
<td><strong>N-band (~ 8.0–13.0 μm)</strong></td>
<td></td>
</tr>
<tr>
<td>Amorphous silicates</td>
<td>9.8</td>
</tr>
<tr>
<td>Crystalline silicates (olivines and pyroxenes)</td>
<td>9.7, 10.6, 11.3, 11.6</td>
</tr>
<tr>
<td>PAHs</td>
<td>8.6, 11.4, 12.2, 12.8</td>
</tr>
<tr>
<td>Fine structure lines (e.g., [S IV], [Ne III], [Ne II])</td>
<td>10.5, 10.9, 12.8</td>
</tr>
</tbody>
</table>
The science cases of MATISSE

Protoplanetary disk

AGN

Evolved stars
MATISSE optical-path
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Principle of MATISSE

Spatial filter
Delay lines
Interferometry/photometry splitter
Anamorphic optics
Filters
Polarizers
Dispersive elements
Camera optics

Beam commutation
Spectral separation
OPD modulation
Delay lines
Spatial filter

L band
N band

Anamorphic optics

Beam configuration
3D 9D 6D

Interferometry/photometry splitter

Spectral separation
Anamorphic optics

L band
N band

Filters
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Filters
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Your Talk Title Here
Principle of MATISSE

Beam commutation
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3D 9D 6D

Beam configuration

Interferometry/photometry splitter

Photometry Units

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Polarizers
Dispersive elements
Camera optics
MATISSE Low Resolution Fringes

L&M bands

N band
MATISSE Fringe coherencing software
MATISSE Fringe coherencing software

Non-zero-OPD Fringes

Clean Fringes

FFTX phase

FFT2D modulus

Fringe peaks waterfall
“First Light” (February 18, 2018)
“First Light” (February 18, 2018)
"First Light" (February 18, 2018)
“First Light” (February 18, 2018)

Betelgeuse

3 µm (L)
5 µm (M)
8 µm (N-)
13 µm (N+)
MATISSE Commissioning

L-band visibility on ATs

L-band Closure phase on ATs

5Jy 4Jy 3Jy 2Jy

σ_{CP} < 1°

σ_{CP} ≈ 3°

Current offered limit
MATISSE performance

Absolute visibility, LR_N, ATs

Measurement dispersion in the 8-9 μm band

Coherent flux at 8.5 μm (Jy)

Broad band V accuracy=0.2, Limit L_c~3 Jy

Broad band V accuracy=0.1, Good seeing limit L_c~4 Jy

Bad seeing limit L_c~6 Jy
Observation in L-Band High Resolution (R=950)

Example on an emission line star

Brα Line Profile (+ Hu 9)

Visibility

Differential Phase

Current Spectral range in HR mode limited by detector read time
DIT=111ms ⇔ 0.1nm
Observation in L-Band High Resolution (R=950)

Example on an emission line star

Could be extended using GRAVITY as external Fringe Tracker

GRAV4MAT
Tests on AGNs

AT L-band Fringes acquisition

\[ \approx 2\text{Jy} \]
Tests on AGNs

AT L-band Fringes coherencing

Coherencing with 5 frames incoherent integration with DIT=75ms ⇔ SNR≈10

≈ 2Jy
MATISSE First Image (December 2018)

PIONIER image of FS Cma (HD45677) 
Circumstellar disk (either B[e] or Herbig)

Imaging Commissioning Run

10 nights of observation

All 4 offered AT configurations:
• Small: 12-35m
• Medium: 40-105m
• Astrometric: 58-129m
• Large: 90-132m

3 main targets (well studied):
• FS CMa: YSO or B[e]? => circumstellar disk
• R Scl: AGB
• Betelgeuse: to test HR imaging capability
PIONIER image of FS Cma (HD45677) Circumstellar disk (either B[e] or Herbig)

L-Band Transfer function in visibility
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MATISSE First Image (December 2019)

PIONIER image of FS Cma (HD45677) Circumstellar disk (either B[e] or Herbig)

L-Band Transfer function in Closure Phase
MATISSE First Image (December 2019)

PIONIER image of FS Cma (HD45677) Circumstellar disk (either B[e] or Herbig)

N-Band Calibrated V as function of spatial frequency

MATISSE MIDI
PIONIER image of FS Cma (HD45677) Circumstellar disk (either B[e] or Herbig)
MATISSE First Image (December 2019)
MATISSE is now ready to do science:
• First observation from the consortium on March 21
• Instrument opened to the community on April 1st

But many improvement are on their way:
• Coherent Integration in N using L-band estimated OPD
  Coherent integration up to several minutes
  Should dramatically improve N-band sensibility

• GRAV4MAT : using Gravity-FT for MATISSE
  Increase L-band DIT beyond 1s
  Especially important for L-band MR, HR, and VHR mode

• Very-high resolution mode : R=4000
  Kinematics in Brα & CO lines 4.6-4.7
This is an happy Astronomer!

Observations should always be that way...