Astronomical Instrumentation at the European Southern Observatory

Mark Casali

- General introduction to instrumentation
- New instruments and opportunities
  - La Silla – Paranal Observatory (VLT)
  - E-ELT
  - Instrumentation R & D

ESO Industry Days 2011
1. Introduction

What do we mean by “Instrumentation”?

Instrumentation
Instrumentation construction

Level of industrial procurements
10 years of change

- Non-astronomical technology developments
  - Adapted for astronomy
  - Computing, optics
- Targeted R&D in institutes and industry
  - Detector developments, deformable mirrors
- Large increase in funds for instruments, matching telescope investments

<table>
<thead>
<tr>
<th>Instruments under development</th>
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</thead>
<tbody>
<tr>
<td>KMOS IR 24-IFU IR spectrograph</td>
</tr>
<tr>
<td>MUSE 1 arcmin square optical IFU</td>
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<tr>
<td>SPHERE high-order AO imager/spectrometer</td>
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<tr>
<td>AOF 4-laser, deformable M2, AO facility</td>
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<tr>
<td>MATISSE LMN band 4-UT VLTI instrument</td>
</tr>
<tr>
<td>GRAVITY K-band precision microarcsec VLTI</td>
</tr>
<tr>
<td>ESPRESSO 10 cm/sec precision optical spectrometer</td>
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</tbody>
</table>
Key technologies

- Cryogenics
- Optics
- Vacuum
- Precision mechanics (also cryogenics)
- Deformable mirrors
- Stiff, light structures
- Imaging detectors
- Low-noise electronics
- Real-time computing
- Control systems and software

KMOS (2012)

*PI – R. Sharples, Durham*

24 2.8x2.8" IFUs, 0.2" sampling.
3 spectrographs (H2RG)
24 cryogenic pick-off arms,
operating on 7.2" field
1 to 2.5 micron operation
$\lambda_c = 2.5 \, \mu$m HgCdTe eAPD

- unlike silicon HgCdTe offers noiseless avalanche gain of up to 33
- 3 successful predevelopment studies with 4-channel 320x256 prototype
- new 32-channel multiplexer in development at SELEX tailored to needs of GRAVITY fringe tracker and AO wavefront sensing

320x256 eAPD array

cryogenic preamplifier
CCD Mosaic for OmegaCAM

- 8 x 4 science mosaic of 2K x 4K e2v CCD44-82 devices
- 268 $10^6$ 15µ x 15µ pixels (0.21 arcsec x 0.21 arcsec)
- + two 2K x 4K CCDs for autoguiding
- + two 2K x 4K CCDs for image analysis (AO and focus)
- To be commissioned in 2011 on 2.6-m VST

Laser Frequency Comb

- Laser Frequency Combs as calibrators
  - Provides a series of perfectly equidistant lines
  - Covers a large wavelength domain
  - Stabilized at the $10^{-11}$ to $10^{-15}$ level
  - The absolute reference linked to an atomic clock
- ESO in collaboration with the MPQ have been developing a LFC calibration system for use in astronomical spectrographs since 2008
- Tested on HARPS

Thorium-argon comb
**Development of Piezo DM technology**

- 52 actuator piezo DM (COME-ON-PLUS)
- 60 actuator bimorph piezo DM (MACAO)
- 189 actuator piezo DM for NAOS
- 50x50 actuator matrix of 1mm pitch
- 1377 actuator piezo DM for SPHERE with its drive electronics

**Large Deformable mirrors development for AOF**

- Ø 1.1m convex
- 1170 actuators
- 29 mm actuator pitch
- 1 ms response
- Stroke 50 / 1.5 μm
Special optics for AO

1.1 m light-weighted reference body for the VLT Deformable Secondary Mirror

1.1m Zerodur shell, in manufacturing

400 mm toric mirror for SPHERE using stress polishing; <1nm rms WFE

Mass = 47 kg

2. New Instruments and opportunities

- VLT
- E-ELT
- R&D

If you are interested in specific opportunities please contact: eso_ins@eso.org
## Scale of instrumentation programme

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLT</td>
<td>5.1</td>
<td>4.0</td>
<td>3.1</td>
<td>3.2</td>
<td>6.6</td>
<td>3.0</td>
<td>3.3</td>
<td>5.0</td>
</tr>
<tr>
<td>ELT</td>
<td>0.2</td>
<td>3.2</td>
<td>3.1</td>
<td>6.9</td>
<td>12.2</td>
<td>12.6</td>
<td>15.4</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>5.1</td>
<td>4.2</td>
<td>6.3</td>
<td>6.3</td>
<td>13.5</td>
<td>15.2</td>
<td>15.9</td>
<td>20.4</td>
</tr>
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### VLT

[Image of VLT observatory]
VLT

- ERIS: AO high-resolution imager/spectrometer
  - Precision mechanical assemblies
  - Stiff mechanical structures
  - Cryogenic Infrared imager
    - Low vibration 40K cooling system

- ESO project
  - Outsourcing to industry and institutes

VLT

- Multi-Object Spectrograph conceptual design studies
  - Two studies for optical and IR instruments
    - Optical and IR fibres
    - Fibre robotic positioners
    - Optics
    - IR and Optical detectors
## Phase A studies identified the key technologies

<table>
<thead>
<tr>
<th>Name</th>
<th>Instrument type</th>
<th>Wavelength range</th>
<th>FoV and sampling</th>
<th>Spectral resolution</th>
<th>AO support envisaged</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICADO</td>
<td>Diffraction limited NIR imager (slit spectroscopy?)</td>
<td>0.9-2.4 μm</td>
<td>30&quot;-5 mas/pix</td>
<td>~4000 (~20.000)</td>
<td>SCAO/MCAO</td>
<td></td>
</tr>
<tr>
<td>HARMONI</td>
<td>Single-field NIR spectrograph</td>
<td>0.8-2.4 μm</td>
<td>1&quot;-10&quot;</td>
<td>10-50 mas/pix</td>
<td>SCAO/LTAO</td>
<td></td>
</tr>
<tr>
<td>EAGLE</td>
<td>Wide-field multi-object NIR spectrograph</td>
<td>0.8-2.4 μm</td>
<td>patrol field ≥60</td>
<td>10-50 mas/pix</td>
<td>MOAO</td>
<td>multiplex &gt;20</td>
</tr>
<tr>
<td>CODEX</td>
<td>High-resolution visual spectrograph</td>
<td>0.35-1.72 μm</td>
<td>point source</td>
<td>&gt;120.000</td>
<td>Tip-Tilt</td>
<td>stability &lt; 2 cm/s over 30 years</td>
</tr>
<tr>
<td>METIS</td>
<td>Mid-IR imager and spectrograph</td>
<td>3.5-20 μm</td>
<td>30&quot;-50 mas/pix</td>
<td>100.000</td>
<td>SCAO/LTAO</td>
<td>Polariometry</td>
</tr>
<tr>
<td>EPICS</td>
<td>Planet finder</td>
<td>0.8-1.8 μm</td>
<td>&lt;5&quot;</td>
<td>&gt;100.000</td>
<td>XAO</td>
<td>Polariometry</td>
</tr>
<tr>
<td>OPTIMOS</td>
<td>Optical MOS (+ imaging?)</td>
<td>0.3-1.5 μm</td>
<td>5&quot;-10&quot; FoV</td>
<td>1000 or 10.000</td>
<td>QLAO</td>
<td>multiplex &gt;100</td>
</tr>
<tr>
<td>SIMPLE</td>
<td>NIR high-resolution spectrograph</td>
<td>0.8-2.4 μm</td>
<td>slit</td>
<td>&gt;100.000</td>
<td>SCAO/LTAO</td>
<td></td>
</tr>
<tr>
<td>IMAGERY</td>
<td>Multi-conjugated AO module</td>
<td>0.8-2.4 μm</td>
<td>2&quot; FoV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATLAS</td>
<td>Laser tomography AO module</td>
<td>0.8-2.4 μm</td>
<td>1&quot; FoV</td>
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### Industrial opportunities: detectors

- **Visible light science detectors**
  - approx. 10-15 4k x 4k low noise CCD detectors
  - 4-6 9k x 9k format sought by optical spectrograph

- **Infrared light science detectors**
  - approx 40 4k x 4k low noise NIR (HgCdTe) detectors
  - 2 1024 x 1024 MIR (5-14um) detectors

- **Near infrared and visible wavefront sensor detectors: fast read-out, low noise**
  - 20 CCD detectors, format 1000-2000k-squared
  - ~5 HgCdTe detectors, format 1000k-squared

### Industrial opportunities: optics

- **The instrument programme will require significant procurement of large optics**
  - (up to ~400mm, lenses and mirrors)

- **Other areas of possible interest**
  - Deformable mirrors of ~80x80 sub-apertures
  - Lenslet arrays for wavefront sensors
  - Micro-optics (mm scale) for integral field units (glass and Al)
  - Optical fibres – high transmission, broadband
  - Large dichroic mirrors

- **Estimated spend on optics ~30MEuros over 2012-2020**
### Instrumentation ELT R&D

- Short time, low risk development & prototyping will be made within the instrument projects
  - Under the responsibility of the project consortium
  - Funded within the cost of the instrument
  - Related milestones will be defined with Consortium

- Longer time, key enabling technologies with higher risk for the project will start before the instrument selection (upon ELT approval)
  - ESO is preparing a long term development plan for instrumentation which will be updated on a two-year basis

### Two First light ELT instruments
**MICADO**: NIR, large field, diffraction limited camera

- PI: Reinhard Genzel, Garching
- MPE, MPIA Heidelberg, USM, INAF, NOVA, OPM LESIA

**HARMONI**: Single IFU, vis-NIR Spectrograph

- PI: Niranjan Thatte, Oxford
- Univ. Oxford, CRAL, CSIC, IAC, UK ATC

**Large Precision Optics**

- Primary arm
- Input focal plane
- Detector array
- Collimator
- Pupil plane filter wheel

**Complex IFU Optics**

- Visible wheel
- Optical support structure
- Quarter modules

Left, the opto-mechanical structure inside the 4-m diam. cryostat.

Above, the integral field unit. The slicer stack is 64x64mm
Possible future ELT instruments

EAGLE: near-infrared multi integral-field spectrometer
Precision cryo-mechanics

- PI: Jean-Gabriel Cuby, LAM
- ONERA, OPM GEPI & LESIA, UK ATC, Durham Uni.

Laser guide star pick-offs
Selection of science sources
MAORY: Multi-Conjugate Adaptive Optics module

- PI: Emiliano Diolaiti, Bologna
- INAF (OABo, OaPd, PA Arcetri) ONERA

'Facility' adaptive optics system supporting two instruments.

Adaptive optics systems

METIS: Mid IR Imager - Spectrograph

cryo-optics & mechanics

- PI: Bernhard Brandl, Amsterdam
- NOVA (Leiden and Dwingeloo), MPIfA Heidelberg, CE Saclay
  DSM/IRFU/Sap, KU Leuven, ATC U
**ATLAS: laser-tomography adaptive optics**

- PI: Thierry Fusco, Paris
- ONERA, OPM GEPI & LESIA

**Compact mechanics/optics**

**CODEX: high stability optical spectrograph**

- PI: Luca Pasquini, ESO
- Geneva Observatory, IAC, INAF, IoA Cambridge

**High-stability vacuum/temp**
SIMPLE: high resolution NIR echelle spectrograph

- PI: Livia Origlia
  - INAF (Bologna, Arcetri, Roma), UAO, TLS, PUC

Stable cryo-optics/mechanics

EPICS Exoplanets Imaging Camera Spectrograph

- PI: Markus Kasper, ESO
- LAOG, LESIA, Uni. Nice, LAM, ONERA, Uni. Oxford, INAF (Padova), ETH Zurich, NOVA (Amsterdam, Utrecht)

High-order adaptive optics & algorithms
OPTIMOS – EVE: Optical-NIR MOS Fiber-based

PI: Francois Hammer, GEPI
NOVA, INAF, RAL, AIP, ZfA Heidelberg, NBI Copenhagen

OPTIMOS-DIORAMAS: Optical slit-MOS + imaging

- PI: Olivier LeFevre, Marseille
- LAM, IAC, IASF-Milano

Precision mechanical systems

Camera entrance pupil ~250mm
END
&
Questions