Science Detectors for E-ELT Instruments

Mark Casali
The Telescope

- Nasmyth telescope with a segmented primary mirror.
- Novel 5 mirror design to include adaptive optics in the telescope.
- Classical 3 mirror anastigmat + 2 flat fold mirrors (M4, M5).

- Two instrument platforms nearly the size of tennis courts can host 3 instruments each + Coudé lab.
- Multiple laser guide stars, launched from the side.
- Nearly 3000 tonnes of moving structure.
Instrument interfaces

Pre-Focal Station

- M6
- Phasing
- Windshake

Multiple concepts
Extensive discussion
Draft ICD now available
### Approved instruments and The Roadmap

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICADO</td>
<td>Fully approved. To be delivered 2024.</td>
</tr>
<tr>
<td>MAORY(mcao)</td>
<td>Fully approved. To be delivered 2024.</td>
</tr>
<tr>
<td>HARMONI/LTAO</td>
<td>Fully approved. To be delivered 2024.</td>
</tr>
<tr>
<td>METIS</td>
<td>Fully approved. To be delivered 2024.</td>
</tr>
<tr>
<td>ELT-MOS</td>
<td>Call for Proposals issued July 2015</td>
</tr>
<tr>
<td>ELT-HIRES</td>
<td>Call for Proposals issued July 2015</td>
</tr>
<tr>
<td>ELT-6</td>
<td>Call for proposals in 2016</td>
</tr>
<tr>
<td>ELT-PCS</td>
<td>To proceed when technology is ready (2019)</td>
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</tbody>
</table>

Science and WFS detectors. Both are important!
**Requirements**

**Wavelength Coverage**: at least 0.5μm to 2.4μm (goal 0.43μm to 2.45μm)

**Field-of View and spatial scales:**
- The instrument shall provide four spatial resolution scales in all wavelength settings.
  - Finest scale: 4 x 4 mas covering an area ≥ 0.5 sq. arcsec
  - Coarsest scale: 60 x 30 mas covering an area ≥ 38 sq. arcsec
  - Intermediate scale(s): 10mas and 20mas

**Transmission**: ≥30% (excluding detector)
## Requirements on Resolving power

<table>
<thead>
<tr>
<th>Resolving power</th>
<th>Wavelength coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 3,000$</td>
<td>$0.5\mu m - 0.8\mu m$</td>
</tr>
<tr>
<td>$\geq 3,000$</td>
<td>$\leq 0.83\mu m \rightarrow \geq 1.35\mu m$;</td>
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<tr>
<td>$\geq 3,000$</td>
<td>$\leq 1.45\mu m \rightarrow \geq 2.40\mu m$ (goal 2.45µm)</td>
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<tr>
<td>$\geq 7,000$</td>
<td>$\leq 0.83 \rightarrow \geq 1.05\mu m$</td>
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<td>$\geq 7,000$</td>
<td>$\leq 1.05 \rightarrow \geq 1.32\mu m$</td>
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<td>$\geq 7,000$</td>
<td>$\leq 1.45 \rightarrow \geq 1.80\mu m$</td>
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<td>$\geq 7,000$</td>
<td>$\leq 1.97 \rightarrow \geq 2.40\mu m$</td>
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<tr>
<td>$\geq 20000 \pm 2000$</td>
<td>$\leq 1.19 \rightarrow \geq 1.30\mu m$</td>
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<td>$\leq 1.54 \rightarrow \geq 1.67\mu m$</td>
</tr>
<tr>
<td>$\geq 20000 \pm 2000$</td>
<td>$\leq 2.10 \rightarrow \geq 2.28\mu m$</td>
</tr>
</tbody>
</table>
MICADO
PI: R. Davies MPE Garching

Precision Imager with 6-laser MCAO

Requirements on Imaging:
- **Wavelength coverage**: imaging observations over a wavelength range from 0.8\(\mu\)m to 2.4\(\mu\)m.
- **Filter set**: 30 filters for imaging.
- **Imager Throughput**: \(\geq 50\%\) averaged within the filter bandpass
- **Pixel Scale**:
  - \(\geq 100\) square arcsecs (400 square arcsecs goal) with a pixel scale of 2mas (goal: 1mas).
  - \(\geq 2500\) square arcsec (3600 square arcsecs goal) with a pixel scale in the range 3-4mas.
- **Astrometric Accuracy**: \(\leq 50\ \mu\text{as} \) (goal: 10 \(\mu\)as) over central field
6-laser MCAO system feeding MICADO and one auxiliary port

Requirements for MCAO

- **Field of View:** $\geq 70''$ diameter unvignettet and corrected.
- **Sky coverage:** required performance over the sky observable by the E-ELT with 50% probability unless otherwise specified.
- **Performance at 2.2µm:**
  - In best conditions Strehl ratio of 0.50 (TBC)
  - In median conditions a Strehl ratio of 0.30 (TBC),
  - In sub-optimal conditions a Strehl ratio of 0.15 (TBC),
- **Transmission:** $\geq 65\%$ (TBC) at all wavelengths in the range 1.0-2.5 um.
Imaging and spectroscopy at L,M,N and Qshort

- **Field of view:** at least $10'' \times 10''$ (goal is $20'' \times 20''$)
- **Imaging transmission:** $\geq 50\%$ averaged over bands
- **Spectral filters:** $\geq 10$ broad and narrow-band filters for each L/M and N/Q imager modules.

Spectroscopy

- **Low spectral resolution:** $R \geq 200$ slit spectroscopy over the entire (L+M) band and over the entire N-band
- **Medium spectral resolution:** $R \geq 2000$ slit
- **IFS wavelength coverage:** L/M band from 2.9$\mu$m - 5.2$\mu$m
- **IFS field of view:** $\geq 0.5$ square-arcseconds
- **IFS spectral resolution:** $R=100,000$ ($\pm 10\%$) at 4.65$\mu$m.
<table>
<thead>
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<th>Instrument</th>
<th>Number of Det</th>
<th>Pixel format</th>
<th>Wavelength um</th>
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<tbody>
<tr>
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<td>9-13</td>
<td>4kx4k</td>
<td>0.8-2.5</td>
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<tr>
<td>HARMONI</td>
<td>8</td>
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<td>4kx4k</td>
<td>0.47-0.95</td>
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<td>1</td>
<td>1kx1k</td>
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<tr>
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<td>2</td>
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<td>6</td>
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Updated 14/10/15
Visible. CCDs.

- Currently do not anticipate any problems
- Formats are all currently available
- Total CCD cost $\ll$ instrument costs
  - barring special specifications

IR detectors (red to 2.5 microns)

- Large number required
- Expensive. Large part of instrument costs
- Not currently available with proven specs

IR detector (3-5 and 10-20 microns)

- Small number required. Specialist development.
Pixel Size

- **parameters**
  - Achievable F-ratio and desired pixel scale on sky
  - diffraction limit
  - Read-noise and max single integration time
  - sky background spectrum and dark current
  - field-of-view
  - science target size

- **Complex trade-off**
HARMONI FoV

For non-AO & visible observations

60 mas × 30 mas

For optimal sensitivity (faint targets)

20 mas

Best combination of sensitivity and spatial resolution

10 mas

Highest spatial resolution (diffraction limited)

4 mas

6.42” × 9.12”

3.04” × 4.28”

~152 × 214 (32000) spaxels at all scales

1.52” × 2.14”

0.61” × 0.86”

4.28” × 6.08”
Using 10 micron pixel detectors risks having a FoV that is smaller than typical object sizes out to redshift 1.5, particularly if you using “nodding-on-IFU” for accurate sky subtraction.
- Imaging, but contains spectroscopic option
- Pixel scales close to diffraction limit have slower f-ratios and pixel size flexibility
- Could accommodate 10 or 15 micron pixels
- TBD
Pixel Size

- Critical in deciding upon detectors and possible competition between manufacturers
- Teledyne 4RG-10 devices much more advanced than 4RG-15 due to NASA WFIRST development funding. And will be less expensive.
- Compromise may reduce detector risk and costs substantially
QE and operability

- >80% for 0.9 to 2.4 microns
- Sharp cutoff beyond 2.5 microns required to reduce cooling requirements
- Substrate removed to remove fringing
- What are acceptable numbers and patterns of dead pixels
  - Expect scattered dead pixels over device
  - Expect worse effects near edges and corners
  - How do they really affect science?
<0.01 e/sec/pixel current spec

Ensures dark current < inter-OH background
E-ELT instruments will have majority of cooling power supplied from large LN reservoirs on the Nasmyth platforms.

- Primarily a vibration prevention measure

Temperatures below ~90K will require pumped nitrogen or mechanical coolers.

- Vibration is a concern for AO instruments and for M1
- Pulse tubes may be a better approach than GM
Read noise

- Not a problem in imaging

- For spectroscopy try to reach shot noise limit in reasonable time with inter-OH background

- Using up-the ramp sampling (or fowler) read noise is reduced much below single CDS read noise – but with noise floor

20 min exposure gives
Read noise ~ shot noise

Would be good to thoroughly understand and possibly improve the noise floor
Well known problem

- Bright or saturated targets lead to decaying remnant signal
- Key item for improvement under NASA WFIRST development
  - <0.01% after 3 minutes

Important to develop lab verification method for spec which properly mimics observational conditions.
Flatness and packaging

- 25 micron P-V @ for HARMONI
- 15 micron P-V @ for MICADO
  - Current 4k devices on molybdenum are in this range, if not better already.
- Can the focal plane be tiled with 2k devices?
- Assembly of arrays of detectors not trivial. Prefer delivery of complete co-planar focal plane. But extra cost.
Si:As N,Q band detectors

Raytheon AQUARIUS

- 1024 x 1024 pixels
- 16 or 64 outputs, from two sides
N,Q band detectors

- Excess Low-Frequency Noise
- Blocking band needs to be thinner
Final thoughts

- Important to understand our instrument detector requirements
  - But unlikely to be able to apply them contractually without great cost

- Important to let manufacturers know which are the crucial requirements for our needs
  - Ensure every requirement is science driven
  - Who carries the risk?
End